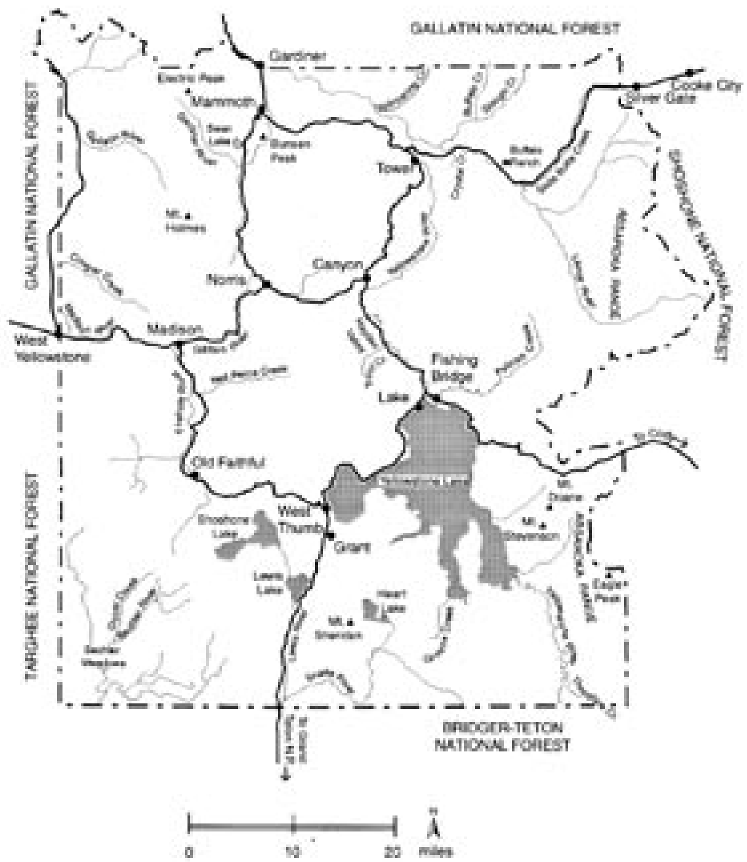
INVESTIGATORS' ANNUAL REPORTS 2002

YELLOWSTONE NATIONAL PARK



YELLOWSTONE NATIONAL PARK

Yellowstone Center for Resources
P.O. Box 168
Yellowstone National Park, Wyoming 82190

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YCR Annual Report: YCR-IAR-2004-01

Cover: An *in situ* growth vial, designed to detect the presence of subsurface microbiota, is attached to a stainless steel cable for deployment into Yellowstone's Well Y-7. Photo by John Spear, Department of Molecular, Cellular, and Developmental Biology at the University of Colorado, Boulder.

Acknowledgements: The National Park Service thanks the researchers that have contributed to our knowledge and understanding of Yellowstone. This report was compiled and edited by Christie Hendrix, Christine Smith, and Virginia Warner.

FOREWORD

The long-term preservation of natural resources makes national parks reservoirs of information of great value to humanity, and perhaps today more than ever before, America's national parks are being recognized as being more than pleasuring grounds and nature preserves. The NPS's Natural Resource Challenge urges that in addition to using science as a means to improve park management, parks can and should be centers for broad scientific research and inquiry.

The national parks have long-captured the imagination of scientists, who recognized them as places where we could observe natural processes operating in places that had been less subject to human alteration than most others throughout the nation, and indeed throughout the world. In Yellowstone, those kinds of observed processes have ranged from macro-scale studies of landscape changes affecting the local ecosystem to micro-scale studies of tiny organisms that have the potential to change the lives of people the world over, making the protection of this wilderness relevant and crucial even to those who will never know its aesthetic and recreational wonders.

There are more than 400 index entries in this year's Investigators' Annual Report. That is a lot of science; a lot of knowledge being collected that needs to be shared. This report should not be seen as the body of that knowledge, but rather as its skeleton. Contact information is provided so that readers may learn more about the projects and results described here. All persons who wish to conduct their own research in Yellowstone are required to apply for a permit. Information on permitting procedures is available from the Research Permitting Office, Yellowstone Center for Resources, P.O. Box 168, Yellowstone National Park, WY 82190, or at <www.nps.gov/yell/technical/research-permits/index.htm>.

Table of Contents

AIR POLLUTION EFFECTS

Project title: Effects of Snowmobile Use on Semi-Volatile Organic Compounds in the Yellowstone National Park Snowpack

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Objective: The objective of this study has been to determine if semi-volatile organic compounds in the YNP snowpack and snowmelt can be attributed to snowmobile traffic. In addition, it was desired to determine whether these compounds accumulate in the snow to levels that pose an environmental hazard and to provide a preliminary estimate of the extent of their persistence in the impacted area. Although the Environmental Protection Agency (EPA) has designated polyaromatic hydrocarbons (PAHs) and other semi-volatile organic species as priority pollutants, there have been very few studies of these species in snowpack. Consequently, this project has included development of reliable methods for sample collection and analysis of semi-volatile species from mobile sources in snow.

Findings: During the winter of 2002, snow samples were collected at five sites situated along the West Yellowstone–Madison Junction road between the West Entrance and the Madison River Road. The samples were collected both on the road and at distances of 3 and 15 meters perpendicular to the road. The sample containers were immediately transported to our laboratories at the University of Utah, Salt Lake City, where they were stored in freezers and subsequently analyzed for total petroleum hydrocarbons. Additionally, thermal desorption gas chromatography coupled with mass spectrometry, to identify semi-volatile organic compounds, and ion chromatographic analysis, for primary anions, was performed.

The method of analysis is as follows. Dichloromethane was used as a solvent to extract organic compounds from the melted snow. Liquid-liquid extractions were carried out in a separatory funnel. After drying with anhydrous sodium sulfate, the extract was concentrated in an extractor/concentrator apparatus, by vaporizing the excess solvent, and the mass of resultant oil and grease was measured by gravimetric analysis. For the samples that have been analyzed, the total weight of the oil and grease extracted lies in the 2–30 ppm (parts per million) range. The highest values are obtained from samples taken on the road closest to the park entrance. The samples taken from sites farthest from the road (15 meters) show the lowest values.

West Entrance samples were analyzed with TOF-SIMS and SEM. This analysis is non-quantitative but provides qualitative assessment of the major components of the aerosol and their size distribution. Few, if any, particles greater than five microns in diameter were observed. In the five 2.5 micron samples, evidence for ash and organic particulate was observed. The majority of particles observed were less than two microns in diameter. Two types of fine particles were observed in the SEM and TOF-SIMS images.

One type of particle, somewhat “amoeba” shaped, seems to resemble the oil soot shown by McCrone and Delly in *The Particle Atlas* except that it is covered by a film. X-ray microanalysis showed C, O, S, and a little K. A strong Al signal showed that the beam was penetrating the particle into the substrate. TOF-SIMS imaging of these same particles revealed that the surface was dominated by high molecular weight n-alkanes and bisulfate. Ion etching of the particles revealed inorganic cores, which contained Na, K, Ca, and Fe. Another type of particle was evidenced only by a very thin black layer, which showed no elements (except background Al) by X-ray microanalysis. It appears that we can see these “black spots” in the SEM solely because they reduce the background Al signal from the substrate. Likely, then, the black spots are made of a light element which gives only a poor X-ray signal. These particles were readily erased by the electron beam. TOF-SIMS analysis of these same particles revealed that they were indeed composed predominantly of high molecular weight n-alkanes and were probably a varnish left on the surface by oil droplets. The analysis of these impactor samples was consistant with the results from the sample collected in previous years.

AIR QUALITY

Project title: Spatial Variation and Characteristics of Volatile Organic Compounds Associated with Snowmobile Emissions in Yellowstone National Park

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Objective: This investigation was undertaken to investigate the types, characteristics, and spatial distribution of volatile organic compounds associated with oversnow vehicular travel in YNP. The intent of the investigation was to establish a set of baseline data associated with levels of oversnow travel that approximate historical peaks in order to document, through future studies, the effectiveness of any reduction in such travel owing to management decisions enacted by the NPS. Additionally, the investigation was intended to serve as a pilot-study designed to test the sampling and analytical methodologies for utilization in future studies to be conducted in the Park.

Findings: The findings suggest that, holding overall levels of snowmobile usage steady, a reduction in the amount of two-stroke snowmobile traffic will likely reduce NMHC emissions including the air toxics benzene and toluene. This scenario essentially represents the Winter Use Plans Draft Supplemental Environmental Impact Statement's Alternative 2. Alternatives 1a, 1b, and 3 will lead to significant decreases NMHC and air toxic levels in the park. The study will continue through 2003, and will include sampling and analysis of particals, oxides of nitrogen, and surface level ozone.

ANIMAL COMMUNITIES

Project title: Predator–Prey Dynamics in a Wolf–Ungulate System

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Objective: The objective of this study is to examine prey selection of wolves on the ungulate populations in the Madison, Firehole, and Gibbon drainages of Yellowstone National Park. Specifically, we are studying predation rates, prey selection, and wolf movements according to landscape attributes, prey abundance and distribution patterns. Aspects of prey selection being studied include species, sex, and age class, condition of prey, and landscape features and snow conditions of encounter and kill sites. The data collected will be used to help predict impacts of wolf predation on the prey populations.

Findings: Data collection for the 2002 field season began in November 2001 and extended through May 2002. Using radio telemetry and opportunistic visualizations, wolves were detected in the Gibbon/Madison/Firehole study area on 134 of 168 days. The Nez Perce pack was detected on 105 days, the Cougar pack was detected on 9 days and an unknown pack was detected on 20 days. More than one pack was detected in the study area on 11 different occasions. Two hundred fifty-four ground based locations, 406 km of snow tracking, and 91 wolf kills were obtained on wolf packs within the study area over the winter. Of the 91 kills found, 75 were elk and 16 were bison.

A methodology for estimating total prey killed by wolves has been developed and validated. The results of this work are currently being submitted for publication. Analyses of wolf movement data and spatial response to landscape variables are currently ongoing. The focus of these analyses is how wolves are responding to environmental variables at different spatial scales. These analyses will be finished by midsummer 2003. A fifth season of data collection has begun and will be completed in early May 2003. Field methods have remained unchanged from the start of this project in 1998.

Project title: Cougar–Wolf Interactions in Yellowstone National Park: Competition, Demographics, and Spatial Relationships

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Objective: Cougar–Wolf Interactions in the Greater Yellowstone Landscape seeks to evaluate cougar ecology and the ecological relationship between cougars and wolves in the Greater Yellowstone Landscape. Through a unique collaboration with the Yellowstone National Park Wolf Project, data are collected by both groups on both species, and both projects are coordinating aerial and ground-based radiolocation efforts. In particular, the project is working to: (1) document characteristics of the cougar population, including predation rates, population size, survival, cause-specific mortality, and natality, and to compare these with analogous estimates made prior to wolf restoration; (2) assess competition and resource partitioning between cougars and wolves by comparing spatial, temporal, habitat, and food use characteristics of the two species; (3) quantify spatial interactions between cougars and wolves; (4) assess the effects of cougars on elk and mule deer populations as influenced by the presence of wolves; (5) communicate research findings to state and federal agencies and the general public through annual technical reports, research updates, and presentations.

Findings: By 2002, we marked approximately 82% of the resident adult population within YNP as a tool to monitor population ecology, predation, and interactions between cougars, wolves, and other scavengers. The northern cougar population, within the protected area of Yellowstone National Park, remained stable at 15–17 resident adult cougars and likely functions as an important source population for other cougar populations within Montana, Wyoming, and Idaho.

In order to better understand how source populations of cougars may be impacted by the presence of wolves, we also monitor reproductive success of Yellowstone cougars, changes in litter size, and survival of offspring through dispersal. A total of 26 of 37 kittens in 15 litters were marked at five weeks to six months of age, 1998 through 2002. Litter sizes ranged from two to four kittens per litter and the sex ratio of litters was one male to one female. One female cougar and one male cougar born on the study area have established a home range adjacent to their natal area. One cougar died during the report period. Resident adult male M139 died as a result of a fall off of a 400-foot cliff while attempting to kill a bighorn sheep ram.

During aerial search flights covering a 200-mile radius, we successfully located six female cougars that dispersed from the study area. Two cougars were located in the southern study area in the North Teton Mountains and east of the Gros Vente. We are currently seeking funding support in order to deploy satellite-tracking technologies on dispersers. The need to monitor detailed movements of emigrants from the Yellowstone population will greatly enhance the identification of dispersal corridors of cougars, wolves, and grizzly bears relative to human development. These data are also important to understanding how the Greater Yellowstone cougar population functions as a genetic link to other cougar populations. We are assisting UM researchers to test whether a virus like FIV (feline immunodeficiency virus) can be used to infer host population structure. Results of this study indicate that FIV occurs frequently, especially in adult cougars and most individuals within a population are infected with related viruses. This research will enhance our understanding of the ecological role of disease in wildlife and may provide new ways to identify patterns of movement among populations, an issue of great importance to conservation.

Cougar predation on prey was documented by investigating kills located by conducting predation sequences of 30 to 68 days, by chance, or via deliberate searches of telemetry location sites. When sex of prey could not be determined, a tissue sample was obtained and sent to a lab for sex determination via DNA analysis. Prey condition was estimated by analyzing marrow fat values of femur marrow sections collected from kills. Project personnel detected 226 positive and probable cougar kills from March 1998 through April 2002. Seventy-one percent of cougar kills were elk, 18% were mule deer and 11% were other prey. Other prey included 4 bighorn sheep, 1 antelope, 7 coyotes, 4 porcupines, 6 marmots, 1 red squirrel, 1 red fox, and 1 golden eagle. Seventy-five percent of cougar-killed prey was scavenged by members of both avian and terrestrial scavenger guilds. Cougars were displaced from their kills by wolves in 8 of 10 documented visits.

We were involved in public and professional meetings including a presentation at The Wildlife Society Montana Chapter Meetings, the Greater Yellowstone Coalition's Annual Meeting, to a group of approximately 20 National Parks and Conservation Association members, to a group of WCS trustees who were visiting Yellowstone and Grand Teton National Parks, and a talk to a group of 16–20 undergraduate and graduate Wildlife Biology students from the University of Minnesota. Toni Ruth and Polly Buotte co-instructed Cougars: Ghosts of the Rockies, a Yellowstone Association field course, July 24–25.

Project title: Collection and Use of Plaster Castings of Animal Tracks to Teach Wildlife Ecology to College and K–12 Students

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Additional investigator: Bruce Eshelman

Objective: We propose to collect plaster casts of animal tracks that we find along the Lamar River and Soda Butte Creek. This exercise will be conducted during a three-credit field course offered through the University of Wisconsin-Whitewater for college students and K–12 educators. We wish to introduce wildlife management techniques such as track interpretation. Participants will be asked to identify tracks (to genus and species if possible), interpret any behavior suggested by the tracks and prepare plaster castings. Many of the participants are, or plan to become K–12 teachers and these techniques will be useful in outdoor education. Selected castings will be used for later testing of the participants during course exams. Selected castings will also be displayed in a comparative and interpretive collection at the University of Wisconsin-Whitewater, Biology Museum. The castings will also be used in the University of Wisconsin-Whitewater Outreach Program for K–12 schools and local Scout troops. The castings are used to make latex negatives for duplication of the original. These duplicates are then used in lectures about wildlife ecology and Yellowstone National Park given by Dr. Clokey (primary investigator). Each year 10–20 duplicate castings are made and distributed to K–12 class during the lecture. All castings are for educational purposes only and are not for sale (they are marked with the collection location, animal, and a statement saying not for sale). Participants in the course are allowed to keep duplicates of castings and are told that they are to be used for educational purposes only. We collect within 200 yards of established trails. We are discreet and clean up all plaster and material. We are aware of and respect the rights and interest of other park users.

Findings: Tracks of several mammals including coyote, wolf, grizzly bear, bison, pronghorn and various birds were studied along the Lamar River and Soda Butte Creek. About 20 plaster casts total were made for several of the species. Selected castings were used for educational purposes at the University of Wisconsin-Whitewater Museum (we kept several good wolf tracks and what we believe to be a mink track for the University display). Students in the course were allowed to keep duplicates of the bear and wolf tracks. We plan to continue teaching the course until 2005 and will seek permission to collect similar tracks at the same locations each year.

ARCHEOLOGY

Project title: Chemical Analysis of Obsidian Sources and Artifacts from the Northwest and Great Plains

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Objective: The major objectives of this research are (1) to establish a geochemical database of obsidian sources in the Yellowstone National Park and adjoining areas; (2) to investigate the geographic extent of primary and secondary deposits of geologic material; and (3) to investigate the patterns of prehistoric use of these sources. Samples are collected and analyzed using three analytical techniques: neutron activation analysis (NAA), energy-dispersive X-ray fluorescence analysis (EDXRF), and inductively coupled plasma-mass spectrometry (LA-ICP-MS). The geographic coordinates and geologic context of each sample is recorded along with the analytical data and will be used to establish the obsidian source boundaries. Artifacts from the United States and Canada are now being analyzed and compared to the source database. This information will be used to examine patterns of procurement and exchange that include the sources of obsidian located within Yellowstone National Park.

Findings: Analysis of source specimens and artifacts using NAA, EDXRF, and LA-ICP-MS methods indicate that all three techniques are very effective for the characterization of obsidian sources and artifacts originating from Yellowstone National Park. In 2002, we continued to add characterized artifacts from Yellowstone sources to our database. We anticipate that the field phase of our investigations of geologic sources of obsidian within Yellowstone National Park will be completed in 2003.

Project title: Miscellaneous Archeological Inventory and Site Evaluations, Yellowstone National Park

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Additional investigator: Paul H. Sanders

Objective: A series of archaeological and historical investigations were conducted under this permit for 2002. These included archaeological inventories along the north side of the Madison River, around the Lamar River Bridge area (Northeast Entrance Road), Brink of the Falls road, Inspiration Point road, gravel pit locations in Swan Lake Flat area, and the powerline corridor from Mammoth to Indian Creek/Gardner River area. Five historic sites were re-recorded along Middle Creek, south of the East Entrance Road, while the historic Glen Creek to Mammoth water supply system was also re-investigated. Data recovery efforts were conducted at the Tower Falls Soldier Station (48YE163). Finally, historic road features along the Virginia Cascades road were recorded.

Findings: Numerous new archaeological sites were identified during the various projects, as well as the re-recording of a number of previously recorded sites. These consisted of a number of historic and prehistoric sites. The historic sites are related to the historic use of Yellowstone. The prehistoric sites are primarily lithic scatters with ages ranging from the Middle Archaic to Late Prehistoric periods. The data recovery efforts at 48YE163, the Tower Falls Soldier Station, identified a trash pit and foundation remains of the officers quarters.

ECOLOGY

Project title: Northern Range Small Mammal Study: Populations Responding to Vegetation Change

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Objective: This study is primarily aimed at providing long-term monitoring of small mammal populations on the Northern Range. The long-term studies will provide data for other past and concurrent studies. This study is a replication of a study performed from 1992–93, thus comparisons will be made on how small mammal populations change with respect to habitat changes over time. This will provide an assessment of habitat effects, species presence/absence in certain habitats and relative abundance of small mammals in the northen range.

Findings: Twenty-five sites were sampled over the summer of 2002. Preliminary looks at the data show some interesting trends. One is the apparent increase in Uinta ground squirrel populations in low coyote use areas. More substantial statistical tests will occur over the next year. A few sites remain to be sampled as a result of bear activity preventing sampling last summer. We will attempt to reach these sites during the upcoming summer.

Project title: Relating *Myxobolus cerebralis* Infection in Native Yellowstone Cutthroat Trout and *Tubifex tubifex* with Environmental Gradients at Multiple Spatial Scales

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Objective: The goal of this study is to determine possible management strategies for native Yellowstone cutthroat trout (YCT) in the Intermountain West. We want to examine spatial and temporal variation in whirling disease (WD) risk to YCT populations, the biological (including infection in tubificids and wild YCT) and physico-chemical factors which correlate with infection risk, and the life history characteristics of YCT that possibly allow some subpopulations or individuals to have low risk of *Myxobolus cerebralis* (causing salmonid whirling disease) infection. Our objective is to examine spatial and temporal variation of disease ecology of YCT at two different scales. First, we want to undertake an intensive study of three streams (Yellowstone River, Pelican Creek, Clear Creek) that previous fieldwork has shown have different levels of infection risk. Second, we will continue the extensive survey that began in 1999 by examining the large-scale patterns of WD risk in and around the diverse stream environments of the Yellowstone Lake basin. This application is part of a long-term project to determine the loss of native age-zero YCT that can be attributed to WD in streams of Yellowstone National Park (YNP) and the Intermountain West each year.

Findings: Wild fry were collected from the Yellowstone River and Clear Creek, although no wild fry were found in Pelican Creek. Post-collection mortality was high for the wild fry collected in the Yellowstone River, but not in those collected in Clear Creek. The sentinel and wild fish have been removed from the Wild Trout Laboratory in Bozeman, MT, where they remained under observation for five months after exposure and collection, respectively. These fish have been sacrificed and are being prepared for histology and polymerase chain reaction (PCR) analysis.

All invertebrates have been picked from the oligochaete samples, and the worms are in the process of being mounted for identification. Near 2,000 live oligochaetes were collected from streams in YNP with over 150 worms collected from the three study reaches. Of these, 46 out of 2,000 and 4 out of about 150 were found to be releasing actinospores; however, PCR tests showed that none of the actinospores were *M. cerebralis*. Although the PCR tests for most of the remaining worms have not been completed, we recently found two worms (one from the Yellowstone River and one from Pelican Creek) that tested positive for *M. cerebralis* using PCR.

In early June 2002, YNP fisheries biologists attempted collection of adult YCT in lower Pelican Creek near the site of the historic spawning migration trap. At one time this trap was used to collect thousands of upstream migrating YCT. Few adult YCT were found in Pelican Creek during what was once a seasonal period of intense use by these fishes. Although we need to examine Pelican Creek even more closely during 2003, evidence from fry and adult collections suggests that we have already experienced a significant loss of the Pelican Creek spawning population. Since *M. cerebralis* has been detected in adult YCT lake-wide, the potential exists for this parasite to cause similar declines in other tributaries. Quantification of environmental characteristics preferred by *M. cerebralis* in the Yellowstone Lake basin will assist fisheries managers in predicting probable areas with high risk of infection. Tributary basins with landscape-level characteristics similar to Pelican Creek include Beaverdam Creek, Trail Creek, and Chipmunk Creek in the remote South and Southeast arms of Yellowstone Lake. This research will assist efforts to preserve these YCT, as Yellowstone Lake and its tributaries represent the last stronghold for what is the largest genetically pure inland cutthroat trout population in the world.

Project title: Influence of Biopollution on Ecosystem Processes: The Impact of Introduced Lake Trout on Streams, Predators, and Forests in Yellowstone National Park

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Additional investigator: Merav Ben-David

Objective: We are investigating the role of cutthroat trout in structuring stream ecosystems, their importance to a representative fish-predator, the river otter (*Lontra canadensis*), and possible effects on terrestrial plants through nutrient transport by otters to latrine sites (Ben-David et al. 1998; Hilderbrand et al. 1999). We hypothesize that the spawning migration of cutthroat trout will result in transport of nutrients from lake to streams, and from streams to terrestrial forests, through the activity of piscivorous predators. Because nitrogen (N) limits production in area streams (J. L. Tank and R. O. Hall unpublished data) and terrestrial ecosystems (Nadelhoffer et al. 1995) we focus our investigation of nutrient cycling on this element. These observations will enable us to predict how streams, trout predators, and the terrestrial landscape will be affected following cutthroat trout decline.

Findings: A total of 13 water samples were collected from Bridge, Cub and Clear Creeks. Analysis of these samples indicated that streams have extremely low nitrate concentrations (below our detection limit of ?g NO3-N/L). This suggests nitrogen limitation and that any added N from fish migration will likely increase primary and secondary production in these streams. Ammonium concentrations and total N are currently being analyzed.

We found a total of 37 river otter latrine sites along streams and lakeshore and characterized 33 random sites. Eighty fresh feces were collected for DNA analysis and 565 old feces for diet analysis. These analyses are currently under way. Density of latrines along streams was 0.35 sites/km of river, and 0.13 sites/km along the lakeshore. In addition, the average number of feces per site per week ranged from 1.25 to 13.1. The density of latrines we found for both streams and lake was relatively low.

For the 2002 field season, the best logistic-regression model identified vegetative slope, large rocks and presence of spruce as the variables most significant in discriminating latrine and random sites on streams. This model correctly identified 76.3% of all locations to their correct affiliation. Otters selected for high presence of spruce and large rocks with shallower stream banks. These results agree with findings of other studies, which found high reliance of otters on old-growth forests and large rocks as aquatic substrate. For lake sites the best model identified shading, forbs, and all other vegetation types (i.e., the category “other” in both overstory and understory) as the variables best separating latrine and random sites. This model correctly identified 81.8% of all locations to their correct affiliation. Random sites were characterized by higher presence of forbs and other vegetation (i.e., latrine sites had higher presence in all other vegetative categories combined), and latrines were characterized by higher amounts of shading. Results from this analysis however, should be interpreted with caution because we had only 12 random sites on the lake. Nonetheless, these results may indicate that river otters select for sites with higher overall vegetative cover that produces extensive shading. We anticipate further elucidating the differences in habitat selection between stream and lake sites by collecting additional data next summer.

In conclusion, our results indicate that habitat selection and levels of activity of river otters in Yellowstone Lake and tributaries are similar to those of otters elsewhere, but numbers may be lower than we initially expected. Whether these lower numbers are related to the decline of cutthroat trout is yet to be established. Alternative hypotheses include: (1) reduction in otter numbers in recent years may be caused by increased concentrations of mercury in stream waters because of reduced water flow; (2) exposure to canine distemper virus from an epidemic in coyotes in the late 1990s caused increased mortality in otters. Two other major gaps in our knowledge exist: (1) the actual number of otters in our study area still awaits determination from DNA analyses; (2) we could not evaluate whether the low numbers around Yellowstone Lake were a result of decreased population size or increased movements of otters into adjacent areas such as the Yellowstone River inlet.

Project title: Application of Stable Isotopes and Trace Elements to Understanding the Potential Effects of Long-Term Changes in Food Resources to Yellowstone Grizzly Bear Productivity

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Additional investigators: Susan Chin, Kerry Gunther, Darren Ireland, Dr. Charles Schwartz, Travis Wyman

Objective: n/a

Findings: Whitebark pine (*Pinus albicaulis*) is a masting species that produces relatively large, fat and protein-rich nuts that are consumed by grizzly bears (*Ursus arctos horribilis*). Trees produce abundant nut crops in some years and poor crops in other years. Grizzly bear survival in the Greater Yellowstone Ecosystem is strongly linked to variation in pine nut availability. Because whitebark pine trees are infected with blister rust (*Cronartium ribicola*), an exotic fungus that has killed the species throughout much of its range in the northern Rocky Mountains, we used stable isotopes to quantify the importance of this food resource to Yellowstone grizzly bears while healthy populations of the trees still exist. Whitebark pine nuts have a sulfur isotope signature (9.2 + 1.3 per mil) (mean + 1SD) that is distinctly different from all other grizzly bear foods that range from 1.9 + 1.7 per mil for all other plants to 3.1 + 2.6 per mil for ungulates. Feeding trials with captive grizzly bears were used to develop relationships between dietary sulfur, carbon, and nitrogen isotope signatures and those of bear plasma. These relationships were used to estimate the importance of pine nuts to free-ranging grizzly bears from plasma and hair samples collected between 1994 and 2001. During years of poor pine cone production, 83 + 16% of the bears made minimal use of pine nuts and meat resources became much more important. During years of abundant cone availability, 30 + 7% of the bears made minimal use of pine nuts while 60 +

13% derived over 40% of their assimilated sulfur (i.e., protein) from pine nuts. Pine nuts and meat are two critically important food resources for Yellowstone grizzly bears.

Project title: The Sustainability of Grazing Ecosystems

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Additional investigators: Peter Groffman, Holly Ewing, Mark Phillips, Len Machut, Freya Ross

Objective: The objectives of the project are to determine the effect of large ungulates on the aboveground and belowground production of grasslands in Yellowstone National Park. Aboveground and belowground production inside and outside permanent exclosures have been measured at 10 sites located at variable topographic positions on winter, transitional, and summer ranges from 1999–2001. Shoot production in grazed grassland was measured using temporary, moveable exclosures and belowground production was determined from monthly minirhizotron images. This last year (2002) was spent catching up on the large volume of root data that had been collected. We also completed a one year experiment that examined the effect of grazers on nitrogen retention in Yellowstone grassland.

Findings: Our overall findings indicate that Yellowstone grazers increase the rate of grassland above- and belowground productivity. This was a surprise to us, because the prevailing view in grassland ecology is that herbivory should inhibit root production, because, according to many pot studies, defoliated plants allocate resources aboveground to recoup shoot losses to herbivores, at the expense of belowground growth. Even more of a surprise was that root production was stimulated seven times more than shoot production, indicating that the predominant effect of herbivores on Yellowstone grassland was to facilitate the flow of carbon belowground. We currently are busy completing the production analyses for 2000 and 2001, two drought years compared to the wet 1999 growing season.

Project title: The Living Stream: Three-Day Course on Stream Ecology to be Taught at the Yellowstone Association

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Additional investigators: Yellowstone Association Students

Objective: To demonstrate to the students how streams function as holistic ecosystems; to collect immature aquatic insects in various size streams; to identify the insects and determine if the functional feeding group composition agrees with those proposed by current stream models.

Findings: Given the restrictions of a single sampling in each stream, we found that the functional feeding group composition agreed fairly well with the predictions of the river continuum concept.

Project title: The Behavioural–Ecological Role of Wolf Howling

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Objective: Wolf howling is one means of social coordination in wolf packs, one way that helps packs function as biological units. This study is designed to test the extent to which the foregoing statement is true. To qualify, howling must: (1) be shown to alter behaviour of the pack or individuals in the pack; (2) that alteration must assist pack fitness by helping it accomplish a task of biological necessity such as procurement of food, raising young, defending territory.

If the beneficiary of howling is the individual, then howling can be interpreted as a trait arising from natural selection. But if the beneficiary is also the pack, then howling can be interpreted, as well, as assisting in group selection.

Group selection is debated in the biological literature as both common among social species, or, as non-existent. Proponents of the latter position invoke an interpretation of cooperative behaviour with advantage to the individual for displays of mutual benefit. Where group advantage has been shown, often interpretations involve kin selection.

The tests of group selection include a sharing to some degree of a common fate, a division of labour, and competition between groups. Superficially, wolf packs seem to qualify. The most fit group may be the one that survives and leaves the most offspring.

The packs at Yellowstone offer an opportunity to compare the use of howling in packs whose unfolding history is and will continue to be known. While many factors undoubtedly contribute to individual and group success, these packs may provide information on differences in their use of howling.

Hypothesis 1: Howling plays a role in group cohesion. Prediction: (1) There will be more howling in both the season of highest group cohesion (most pack members together or close to one another), and the pack that shows the highest cohesion. Possible outcomes: Howling high when cohesion high, and howling low when cohesion low. (Not a definitive outcome because other factors could be responsible.) Howling high when cohesion low, or vice versa. Disproves hypothesis. (2) There will be a set of observations of cases where howling of distant pack members brings them together, versus a set of observations where howling does not bring them together. (3) Howling will be more frequent when some pack members are known to be absent versus all present, or when alphas are absent.

Hypothesis 2: Howling acts to coordinate pack movements. Prediction: There will be a set of observations of wolves bringing pack members together either when the pack is traveling, or to initiate travel, or at a kill or rendezvous site or den.

Hypothesis 3: Howling acts to identify pack members to each other versus non-pack members. Prediction: Set of observations of: wolf howling as wolf comes in to rendezvous site, den, or kill where the rest of the pack is present; ambivalent behaviour of approaching wolves broken with a howl (pack members show acceptance, non-pack members show avoidance); packs near each other, or aware of each other, separate more after a howl.

Hypothesis 4: Group howling aids in social bonding/social partitioning. Prediction: Set of observations associated with play or group social display (before play or to initiate it, part of it, terminate a bout of it) or when pack members arrive or leave the rest of the pack.

Hypothesis 5: Howling aids in territorial defense. Prediction: (1) Sets of observations of packs aware of each other, howling (versus packs not howling). (2) Group howling more common (howls per minute of observation) at kills near territorial boundaries than distant.

Findings: Fieldwork was conducted October 8–13. During that time we recorded seven howling sequences and noted one other recounted to us by Rick McIntyre.

Of the eight sequences, five were of two or more wolves. For four of these five, the wolves were under our observation. Once the Druid Peak pack howled from its rendezvous site with no obvious trigger or effect on movements other than a general milling around during the howl. Another instance was the howls of four wolves from the Garnet Hill pack, including both alphas, at a kill-site which was elicited by distant howling from probably other members of the same pack. That howling was followed by the four wolves running up the slope in the direction of the howls, but the meeting was not observed. Another instance was the Druid Peak pack at its rendezvous site when it was disturbed by two people walking directly into the site. The wolves scattered, then howled from various distant points. Most persistent howler was alpha male #21. Another instance was seven of the Geode Creek pack including alpha female #106 that howled while resting on a knoll. Finally, not observed by us, but by Rick McIntyre, were two Garnet Hill wolves at the kill mentioned earlier.

These five sequences fit categories of group howling with: no cause-effect, locational, and disturbance. Subjectively, the howls given by the disturbed wolves were no different that those given with no cause-effect: long and sonorous with little pitch variation.

Single howling was recorded from a Druid pup in two contexts, once when left behind by the pack and following its scent trail but stopped by encountering the scent of the nearby Geode Creek wolves, and on a second occasion while left alone in the Druid rendezvous site the next day. The former fit the category of extreme anxiety, the latter of "malaise." The howls were very different, the former short (less than three seconds) and treble, the latter longer with pitch-drops. In addition, we recorded the howls of an unknown single wolf, occasionally with another wolf, over the course of half an hour—probably members of the Geode Creek pack. We do not know the context as they were out of sight.

Sub-optimal recordings are the result of distance, wind, and the noise of traffic and people talking and slamming vehicle doors. The quality of recordings made will allow auditory analysis, but not computer analysis.

Project title: Effects of Fires on Ecology of Coyotes in Yellowstone National Park: Baseline Succeeding Wolf Recovery

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Objective: Document long-term effects of the 1988 fires on the population dynamics and behavioral ecology of coyotes. Document the long-term impacts of wolf restoration on coyote populations and coyote behavioral ecology, including effects on coyote prey abundance, and competitor species. Continue long-term monitoring of coyote populations by adherence to those objectives listed in previous reports and peer-reviewed publications, including: pack size, individual identification, social class, home range assessment, mortality rate, litter size, vocalizations, scent-marking, predation on small mammals and ungulates (and neonates), interactions with other species including ungulates, interactions with scavengers at carcasses, and radio-tracking.

Findings: This long-term project began phase III in 2001 (Phase I: pre-wolf, Phase II: wolf colonization, Phase III: wolf establishment). Each six year phase provides a new segment of a rare long-term ecological study. The long-term impacts of fires (during Phase I) investigated indirect effects via the small mammal prey base but now these effects are diminishing. A variety of significant demographic and behavioral effects of wolves on coyotes continue to occur. In 2002, 27 resident adult coyotes occupied the Lamar Valley and Little America study areas, a population level which continues to be consistent with the reduction post-gray wolf restoration. On the Blacktail Plateau study area, the coyote population also continues at a level which is reduced by approximately 50% from pre-wolf levels. In 2002, we relied upon six to eight radio-tagged coyotes to aid in estimation of numerous demographic parameters and facilitation of behavioral observations. Our trapping efforts in 1996 through 1999 yielded 48 radio-tagged adults on which to base our efforts. Since 1999, the number of radio-tagged adults has decreased because of the approximate three to four year battery life of collars. Another capture and marking effort is now needed to complete Phase III described above as well as to continue and standardize this long-term study.

The primary novel findings during the 2002 year were the effects of large wolf packs on the availability of scavengeable ungulate carcass remains for coyotes. Coyotes' scavenging opportunities at ungulate carcasses were much reduced in the year 2002, as a result of the increased wolf pack size and density observed in the Lamar. Larger wolf packs consumed ungulate carcasses more rapidly, leaving less available biomass for coyotes. This decrease in carcass biomass likely affected coyote productivity as litter size counts were very low in 2002 (1.8 pups per pack). In addition, other important prey items, namely Uinta ground squirrels and vole (*Microtus* ssp.) populations, were high and low (no recorded captures or field sign), respectively. Wolf caused mortalities of coyotes continue to occur, again primarily associated with ungulate carcasses.

Results from survival analysis of radio-tagged coyotes (in prep.) indicate a number of novel findings. In addition, we are preparing a number of manuscripts that compare Phase I (pre-wolf) with Phase II (post-wolf) results.

Project title: Landscape Use by Elk During Winter on Yellowstone's Northern Range

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Objective: The objectives of the study were to document winter patterns of landscape use by elk on YNP's northern range (as indexed by snow feeding craters), quantify snowpack characteristics, and how these and other landscape and habitat features influence foraging locations and movements. In addition estimate of these parameters will be incorporated into an ongoing energetic elk model. How does snow effect the distribution and movements of elk during winter? What factors, such as winter forage availability, predator density, snow depth, slope, snow density, are affecting their distribution?

Findings: We measured site and snowpack characteristics, elk (*Cervus elaphus*) feeding crater densities, densities and morphometry, and elk numbers in the Lamar River valley and the Blacktail Plateau on the northern range of Yellowstone National Park during three winters, 1992–93 to 1994-–95. Snow depth, snow water equivalent (SWE) and snow resistance to horizontal movement and vertical penetration all increased steadily over the winter. The mean (SD) feeding crater diameter and depth was 118 (37) cm and 34 (11) cm, respectively, and both were positively correlated with snow depth. The mean (SD) crater volume was 385 (321) liters, and the mean (SD) mass of snow excavated from a crater was 82 (72) kg. Non-woody plants (grasses, sedges and forbs) were the primary browse item in 90% of the craters. The highest aerial elk counts were observed in early- to mid-January, and counts declined substantially and steadily after 29 January. At this time, mean snow depth was about 50 cm and mean SWE was about 12 cm. The mean number of new craters on a plot showed a significant, negative association with snow depth, SWE and booted-foot sinking depth. We used the sum of craters on a plot across all four sample periods as an index of winter long feeding activity. Elevation and habitat type were the best site characteristics for differentiating plots in regard to winter-long use. Summed craters were negatively associated with elevation, and the habitat type with the highest summed craters was tufted hairgrass/sedge. Only about 5% of plots that had craters had areal crater coverage in excess of 14%, with a maximum of 23% coverage, suggesting that snow disturbance associated with cratering activity may inhibit elk foraging. We are preparing manuscripts for publication and amending the original elk–snow model developed in 1999. Fieldwork began in November 2002 with snow measurements taken at the original 1992–95 sites in Lamar and Blacktail. Early winter 2002 so far has been an unusual situation and field data appear to represent the foraging patterns of elk given little or no influence by snow.

Project title: Carnivore Detection Survey

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Objectives: (1) Assess current field techniques to inventory and monitor medium-sized carnivores: weasels, otter, wolverine, marten, fisher, lynx, bobcat, mountain lion, fox, coyote, and gray wolf; (2) examine various habitat and landscape characteristics related to their presence/absence; (3) conduct presence/absence surveys in Yellowstone National Park and surrounding wilderness areas.

Findings: With the notable exception of three decades of research on grizzly bears, and more recent studies on mountain lions, pine marten, and coyotes, we know very little about Yellowstone's mammalian carnivores. Members of the order Carnivora are typically secretive, nocturnal and exist at low population densities. In many cases, we do not even have reliable methods to determine presence let alone estimates of abundance and other important demographic parameters. During the winters of 1990 through 1997 we conducted detection surveys and evaluated three methods: hair snares, remote camera stations, and snow track transects. Their utility as estimates of presence, distribution, and abundance were evaluated, as well as their cost, maintenance, reliability, precision, and bias. Response to hair snares and camera stations were variable locally and between years. Hair snares have the exceptional advantage of providing DNA samples and potentially identifying individuals, but have the disadvantage of relatively high maintenance and cost and provided unreliable results from the analysis of hair characteristics. Camera stations, like hair snares, performed well in adverse weather and can identify individuals, but suffer from avoidance bias by several resident species. Camera stations were costly in terms of expense and maintenance. Snow track transects identified four species not detected by other methods and were simple, low cost, and low maintenance. They provide precise habitat information, whereas camera stations and hair snares are baited with food and scent lures which bias results concerning habitat use. Snow track transects allow researchers coverage of large areas and habitat types and can provide valuable information if scats are found and if DNA is successfully extracted. The reliability of species identification from snow track transects is a disadvantage due to poor climatic conditions and the similarity of many species' track characteristics. Although the specifics of objectives and logistics should dictate use of these methods, we suggest a variable combination of all three methods for determining presence and distribution. All methods have significant problems, especially when inferring abundance. Determining relative habitat use from snow track transects proved reliable and matched that known from previous studies. Multiple copies of the final report have been sent to the Yellowstone Center for Resources at Yellowstone National Park and we are preparing a manuscript on the evaluation of three detection methods for medium-sized carnivores. This project resulted in the confirmation of fisher in the Yellowstone Ecosystem.

Project title: Climate Effects on Small Mammals: A Multi-Scale Approach to the Study of Mammalian Response to Global Climate Change

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Objective: Our ability to predict the effects of global warming on biotic communities ultimately depends on our understanding of how individual species track specific climate variables at multiple scales. The purpose of this study is to gain insight into biotic response to climate change by characterizing the effects of climate on ground squirrel distribution, body size and population dynamics. Specifically, I hypothesize that temperature limits the distribution of *Spermophilus armatus*. To test this I will examine both present and historical patterns of distribution. First, I will use GIS data in conjunction with digitized locality data to perform statistical correlation analyses to determine if temperature correlates with the present distributional boundaries of the species. Second, to determine if there has been local extirpation and /or species replacement in response to the climate fluctuation of the late Holocene, I will perform phylogenetic analyses of ancient DNA sequences from specimens excavated from Lamar cave, a paleontological site in Yellowstone National Park. I also hypothesize that the effects of temperature will affect ground squirrel biology at the population level. I predict that in addition to range shifts, one of the ways in which ground squirrels respond to changes in temperature is by proximate and local changes in body size. I will test this in two ways. First I will examine the population level, phenotypic response of *S. armatus* to changes in the regional climate during the late Holocene by tracking changes in the body size of specimens from Lamar Cave. I will also study the distribution of body size along an elevational gradient. Changes in body size have direct and predictable effects on life history characteristics and thus on population dynamics. In order to gain insight into the mechanistic processes that explain these broader patterns of response I will develop and test a model that examines how the energetics of the individual are effected by the local thermal environment. Ground squirrel of the genus *Spermophilus* are particularly useful for studying biotic response to climate change because they are obligate hibernators and they show sensitivity to environment cues such as temperature. In addition, ground squirrels do not migrate therefore changes in abundance, distribution or the timing of life history events reflect response to local climate phenomena. Ground squirrels are also a vital link in terrestrial trophic interactions. As such, changes in ground squirrel abundance and distribution are likely to affect other species that prey on them. Thus ground squirrels may prove to be a useful indicator species for tracking the effects of current climate change at the local level and for predicting the effects of climate change on the community.

Findings: As part of an effort to better understand how microclimate effects the body size, distribu tion and population density of small mammals, we trapped, measured and marked individual ground squirrels from four sites along an elevational (and thus temperature) gradient. Our field research in Yellowstone National Park was conducted intermittently from April 1 to August 6, 2002. Three of our sites were within the boundaries of the park. At each site we set up a trapping grid of 150 ft x 245 ft and laid out 21–40 Sherman live traps (XLF 15). Each captured animal was given a unique ear tag number. Sex, age and standard body size measurements including: body mass, total length, tail length, hind foot, ear from notch, forearm length and zygomatic width were taken for each animal captured. Body mass was recorded every time an animal was captured. Recaptured animals were completely re-processed four times to check the accuracy and repeatability of our measurements.

Microclimate data was collected at each site using a Davis Instruments Advantage Pro weather station. Climate data collected included: ambient temperature at ground level, 6 inches, and 2 m; wind velocity and direction; solar radiation at 6 inches; and rainfall. Climate data was collected in 30-minute intervals. We also collected genetic samples from ear punches of every individual captured to use in a genetic analysis of the genetic diversity across the elevation gradient. Ear punching is a low-impact, non harmful method of genetic sampling that is widely used among mammalogists. The genetic data will allow us to calculate effective population size, assess the level of genetic diversity presently represented at the sites.

To determine if burrow density is a good measure of population density we counted the number of burrows in the trapping grid at each site and compared that to the population density estimates obtained by the capture/recapture data. In addition we mapped the location of each burrow with a Trimble GPS unit and recorded descriptions of the burrow entrances. Colony density in the region surrounding my research sites was assessed by doing linear transects. Presence or absence of colonies was recorded along the transects also using a Trimble GPS unit.

The following is a summary of our 2002 research with a brief description of our preliminary findings. Site 1 is located about 0.5 miles up the old Gardiner Highway from the North Entrance Gate. We worked there from April 1–27, June 11–16, and July 30–August 3. The first ground squirrel emerged at this site on April 12. Over the course of the active season we caught 13 adults and 9 juveniles. We trapped for a total of 2,361 trapping hours. Site 2 is located very near Lamar Cave about 4 miles south of the Slough Creek Campground. We worked there from July 28–29 . We trapped for a total of 450 trapping hours and captured 8 adults and 9 juveniles. Site 3 is located just across the Lamar River from Site 2 near Junction Butte. I worked there from April 1–27, June 2–6, and July 24–27. The first ground squirrel emerged on April 6. We trapped for a total of 2,017 trapping hours and caught 51 adults and 11 juveniles.

To compare the morphologic measurements between sites I first separated the data by sex and age. I then performed a series of One-Way ANOVAs to test for significant differences in body size between the sites. Preliminary analysis of the morphologic data indicates that there are significant differences in the body size of ground squirrels between the four sites and that population density varies between the sites as well. Burrow density also varies dramatically between sites but does not correlate with the number of individuals caught at each site. However, I am still calculating population density using the capture and recapture data and final assessment of population and burrow density is still necessary.

Project title: Post-Burn Resource Selection, Physiological Condition, and Demographic Performance of Elk

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Objective: The primary objective of this research is to evaluate the selection of resources by elk under forest succession and the pressure of a temporally and spatially dynamic snowpack. The physiological and demographic consequences of observed resource selection strategies are being assessed through non-invasive urinary and fecal assays, and telemetry. Secondary objectives include basic research on forage plant chemical compositions, plant–animal interactions and applied research to develop practical and rigorous management tools for population monitoring (aerial surveys, fecal steroid pregnancy assays, and snow–urine condition indices).

Findings: We have been successful in developing, testing, and applying a suite of research tools that is significantly enhancing our ability to address questions of animal resource selection and the physiological and demographic consequences of selection patterns. We have completed our eleventh field season of data collection and maintain an instrumented population of 30–40 cow elk. Most publications to date have focused on techniques including population estimation, pregnancy assessment, and nutritional indices. This year we completed a manuscript analyzing the demographic data collected during the first seven years of research, which is currently in press in the *Canadian Journal of Zoology*. Adult survival and reproduction is near the biological maximum for the species, but recruitment is highly variable, being strongly influenced by environmental variation, primarily winter severity. Despite this variable recruitment, extensive Monte Carlo simulations indicate that the population is relatively stable and is being regulated at approximately 600–800 animals. An additional manuscript, examining geo-chemical influence on elk demographics, was published in *Ecosystems*. Exposure to high concentrations of fluoride and silica result in aberrant tooth wear and result in the early onset of senescence, reduced life span and an abbreviated age structure of elk in the Madison Drainage. We have generated a database of greater than 11,000 animal locations and are exploring a variety of analytical tools for the analysis of these data. We continue to acquire and develop GIS data sets of landscape features for integration with all spatially explicit data collected on this study. In collaboration with NASA scientists we have developed spatially and temporally explicit snowpack models for our area, as well as the first remotely sensed geothermal inventory of Yellowstone. Results of recent work can be found at two web sites:
<http://www.homepagemontana.edu/~rgarrott/centralyellowstone/index.htm>,
<http://earthsystems.csumb.edu/~fwatson/ >, follow link to "projects", then "Yellowstone."

Project title: Climatic Variation in the Greater Yellowstone Ecosystem: Evaluating the Evidence for Decade to Centennial Variability in Climate

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Objective: Our objective is to investigate the record of climatic variability in the Greater Yellowstone Region (GYR), to enhance our understanding of regional patterns and processes. The climate record will be reconstucted by climatically sensitive tree-ring chronologies. For example, studies of the interactions between climatic variability, fire, and grazing in regulating forest stand structure and composition (e.g., Romme et al. 1995) will be enhanced by longer and more detailed climatic histories of the region. Similarily, research on interactions of fire, climate and geomorphic processes (e.g., Meyer et al. 1992) will benefit from better information on climatic trends and variability. Finally, long-term histories of climate can inform the monitoring strategies for assessing the impact of global environmental change on mountain regions (Romme and Turner 1991; IGBP in press).

Findings: Climate variability, coupled with increasing demand is raising concerns about the sustainability of water resources in the western United States. Tree-ring reconstructions of stream flow that extend the observational record by several centuries provide critical information on the short-term variability and multi-decadal trends in water resources. In this study, precipitation sensitive Douglas-fir (*Pseudotsuga menzeisii*) tree ring records are used to reconstruct annual flow of the Yellowstone River back to A.D. 1706. Linkages between precipitation in the Greater Yellowstone Region and climate variability in the Pacific basin were incorporated into our model by including indices of the Pacific sea surface variability, namely the Pacific Decadal Oscillation and the Southern Oscillation. The reconstruction indicates that twentieth century streamflow is not representative of flow during the past three centuries. With the exception of the 1930s, streamflow during the twentieth century exceeded average flows during the last 300 years. The drought of the 1930s resulted in the lowest flows during the last three centuries, however, this probably does not represent a worst-case scenario for the Yellowstone as other climate reconstructions indicate more extreme droughts prior to the 18th century.

Project title: Determining Forage Availability and Use Patterns for Bison in the Hayden Valley

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Objective: (1) Determine seasonal habitat use patterns for bison in the Hayden Valley and factors that influence these patterns; (2) identify interactions between bison and vegetation; (3) develop a monitoring strategy to track changes in vegetation due to ungulate herbivory; (4) provide baseline data for models of ungulate-vegetation relationships in the Hayden Valley.

Findings: (1) As expected, bison in the Hayden Valley relied on graminoids as their primary food. Sedges were the most abundant graminoid group in fecal samples. Other important graminoids included Idaho fescue and poas. When we compared nutritional quality of selected graminoids with intake, the overall pattern suggested bison were selecting for protein content, total digestible nutrients, and/or moisture. Apparent utilization (differences in biomass between caged and uncaged plots) data in common habitat types suggest that during the growing season, bison selected dry sites with graminoids dominated by Idaho fescue, wheatgrasses, and/or native poas. Over the entire growing season, these types had, on average, two times greater percent offtake than sites dominated by mesic sedges, tufted hairgrass, or oatgrass.

(2) Fecal counts and visual observations indicated that bison were responsible for >90% of large mammal herbivory in the Hayden Valley. The highest estimated percent forage removal by herbivory over the growing season generally occurred in upland types, with the highest overall removal (based on three years of monitoring) in ridge top vegetation (54.7%). Lowest percentage offtake (<20%) occurred in the two moistest types (wet sedge and hairgrass/sedge). The amount of offtake (grams removed by bison) varied substantially within types, but differences among types were not significant. As expected, biomass of standing crop in cages was significantly different among cover types, with the greatest amounts in wetter types and the least amounts on hillsides and ridgetops.

(3) Our data indicate that some of the drier graminoid communities in the Hayden Valley sustain >50% offtake during the growing season. This is close to maximum recommended rates of removal in many cattle management systems, but we were unable to detect any trends in productivity or plant species composition in the Hayden Valley over the 3 years in which we monitored vegetation. We also found that exotic invasive plants were rare in areas removed from roads, but bison rubbing was producing mortality in conifers along the edges of the valley. Although our data did not indicate that plant communities in the Hayden Valley were declining in quality, common sense dictates that sampling species composition in the heavily used dry upland communities, surveillance for invasive exotics (weeds), and use of satellite imagery to monitor changes at the boundary between steppe and forest would be logical approaches. Our work with multispectral radiometry indicates that satellite-borne radiometers could be used to monitor changes in productivity in graminoid and shrub communities over time.

(4) Data we collected from cage experiments and multispectral radiometry have been sent to Dr. Michael Coughenour (CSU) who is building a spatially explicit model of ungulate–vegetation interactions for YNP.

Project title: A Proposal to Cooperatively Monitor and Assess Wolf–Ungulate Interactions and Trends in Selected Locations within the Greater Yellowstone Ecosystem of Montana

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Objective: This project will measure the impacts on population dynamics of the responses of elk to the risk of predation by wolves. Specifically, we will: (1) monitor population sizes of elk on several study areas in the GYE; (2) monitor wolf predation pressure (kill rates, levels of use) on these sites; (3) monitor demographic changes in the elk populations on these sites—composition surveys, pregnancy rates from endocrine data, and mortality rates for radiocollared elk will provide these data; (4) monitor habitat selection and space use by elk, in relation to wolf movements; (5) monitor behavioral responses to predation risk; (6) monitor elk nutritional status using urinary allantoin:creatinine ratios, and physiological stress responses using fecal glucocorticoid levels; (7) monitor changes in elk diet associated with behavioral responses to predation risk from wolves.

Findings: The project has now collected one preliminary and two full years of data pertinent to its objectives. On the Gallatin Canyon study area we have deployed more than 50 radiocollars on elk, including 16 GPS collars, and all of the sampling schemes necessary for the seven objectives are in place.

The project is funded by the National Science Foundation through 2007.

Project title: Rocky Mountain Field Ecology

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Objective: Our objectives for this three-week field course were (1) to introduce upperclassmen students to the ecology of the Rocky Mountains through field investigations of plant and animal interactions; (2) to explore issues of conservation and resource management by examining specific case studies from the Yellowstone Ecosystem; (3) to design, conduct, analyze and present independent observational field research; and (4) to experience the culture, attitudes, and history of the American West.

We presented six formal lectures on the history, climate, wildlife, fire ecology, northern range controversy, and wolf reintroduction. We conducted three formal field lab activities, a comparison of aspen sucker height in browsed and unbrowsed sites, a comparison of elk vigilance in low and high wolf predation sites, and a comparison of lodgepole density in moderate and severe burn sites. We hosted several evening guest speakers including Dr. Jay Anderson and Mark Lung of Idaho State University; Demetri Videgar, Idaho Fish and Game; Ralph and Sue Glidden, Cooke City General Store; Scott Sanders, Big Bear Lodge; Dan and Cindy Hartman, Wildlife in the Rockies Photography. We visited several interpretive centers including the Albright Visitor Center, the Yellowstone Institute, and the Cody Wildlife Art Museum. We hiked several park interpretive trails at Canyon, Norris Geyser Basin, Midway Geyser Basin, Lower Geyser Basin, Mud Volcano, Tower Falls and Rose Creek.

Findings: Our 13 undergraduate students, 2 graduate students and 2 faculty members thoroughly enjoyed the three-week stay in Yellowstone. We stayed outside of the Northeast park entrance in private accommodations and traveled into the park daily in two vans (one university and one rental). All students were eager and active participants in all planned and unplanned activities. Data collecting took place in the Lamar Valley, Blacktail Deer Plateau, Swan Lake Flat, Norris Campground, Gibbon Meadow, and Hayden Valley. All data collection was observational and did not involve collecting any specimens. We measured aspen sucker density and height, elk pellet and bison scat density, elk feeding and vigilance, lodgepole density and height, ground squirrel and pocket gopher burrow density, and flowering plant composition and density. Students in groups of three to five developed an independent project, collected and analyzed the data and made a final project presentation to the class on the last night of the course. Overall, the projects and presentations were excellent in terms of content, effort and scientific interpretation. We felt the students learned a great deal about how field biologists conduct research on the tough conservation and management issues facing the National Park Service. Students also submitted a written project report two weeks after we returned home as part of their course requirement. We felt our course accomplished all our objectives described above and that the students had a once-in-a-lifetime field research experience.

Project title: Natural Experiments with Height Releases of Willows

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Objective: The objective of this second, but supportive proposal is to investigate two major aspects of this apparent recent height release of willows. (1) To quantify browse levels and any height release of willows on a sample of 14 permanently marked willow sites (2–4 transects per site) that were sampled following 6–8 winters in the pre-wolf era (1985 to 1991 or 1993); and a randomly selected landscape-scale sample of about 25 additional willow patches. We propose to quantitatively document changes in willow growth, height, and browse intensity on these willows before and after the introduction of wolves. (2) To correlate several potential factors related to the height release of some willow patches. We propose to relate several factors (elk abundance, elk browsing intensity, wolf activity areas, winter snowpack, and weather patterns) to the height release that is occurring on some, but not all, willow patches.

Findings: In the 2002 field season, we gathered data on ungulate consumption rates and stand characteristics (suppressed, height released, escaping browsing) from 40 willow stands on the northern range, including 10 stands which had been measured 1988–92. We surveyed the entire length of seven drainages to locate, map, and characterize willow stands within these drainages: (1) Blacktail Deer Creek from the sources to the Yellowstone River; (2) the Beaver Pond Complex near Mammoth and related creek from the source to Gardiner River; (3) Geode Creek; (4) Slough Creek; (5) Lamar River from Slough Creek to Soda Butte Creek; (6) all of the Crystal Creek complex; and (7) Soda Butte drainage from Lamar River to above Round Prairie (to park boundary is lower priority). We sampled seven sites where willow thickets have developed or begun to develop to attempt to determine the characteristics of these thickets. We sampled basal root cores from 40 willow plants to determine age and years of previous growth releases. We sampled stems from ~50 plants currently showing signs of height release to determine the year this release initiated. Data are currently being entered into electronic format and will soon be analyzed. Basal root samples are currently being processed (cut, sanded, and aged). Production was measured on a sub-sample of plots, which had been monitored in the late 1980s and early 1990s.

Project title: Multi-Trophic Level Responses to the Addition of a Top Carnivore

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Objective: This study is examining the ecological changes associated with re-establishment of wolves in Yellowstone National Park in 1995 and 1996. Species representing three important trophic levels—wolves, elk, and woody vegetation—are the focus of the research. The specific areas of interest are: (1) spatial and temporal patterns of abundance of the newly introduced top carnivore (gray wolf), the dominant herbivore (elk), and woody vegetation on YNP's northern range; and (2) mechanisms underlying trophic dynamics, especially predation rate of wolves and herbivory use by elk on woody vegetation.

Findings: In February 2002, we captured 20 more cows and recaptured 4 GPS-collared cows whose collars did not drop off as programmed. In 2002, 8 radiocollared elk died: 4 elk were taken by hunters (50% of total mortalities), 2 by wolves (25%), and 2 died of unknown causes (25%). All but one of these mortalities occurred during the winter.

Relocation flights began on June 21, 2000, and have continued on a regular basis. As of January 6, 2003, there are 37 radiocollars on the air: 36 VHF collars and 1 GPS collar. Recently 9 GPS collars released by their remote removal mechanisms and were retrieved from the field.

As of December 20, 2002, we have accumulated 3,589 elk locations from the 97 elk that have been monitored over the first three years of the study, yielding up to 79 locations per individual elk.

Based on data from GPS-collared elk and also from regular VHF tracking of the collared animals, we documented the current major migration routes of the northern elk herd. Elk travel from their wintering grounds on the northern range to areas as far south as Lewis Lake, east to the eastern border of the park, and north onto the Buffalo Plateau. A small number of elk remain on the northern range even during the summer. Of those that migrated, most elk return to the winter range in mid-October through mid-November usually in response to snowfall.

The migratory patterns of the herd segment that summers in the Lewis Lake area were not known based on data from 2000, but because of our larger sample of radiocollared elk in 2001 and 2002, and because of the continued aerial tracking of these animals, new information on their movements was found. These long-distance travelers migrate via the Washburn range/Carnelian Creek region and, remarkably, they can make their 70-kilometer journey between the Northern Range and the Lewis Lake area in under four days. All of the elk returned to the northern range by late November.

A preliminary analysis of habitat selection by elk was done to compare pre-1988 fire/pre-wolf, post-1988 fire/pre-wolf, and 2000 to early 2001/post-wolf periods. A herd-wide, landscape-scale model of summertime habitat selection showed elk selected for areas of higher elevation, intermediate slope, and southeast to northeast aspects. Elk also selected for grass-forb communities and burned forested areas and they selected against areas of mature conifer forest.

Comparing pre-wolf and post-wolf habitat use, the only major difference detected thus far between these time periods was that elk currently select higher elevations during the summer. This difference could be a result of elk moving to higher elevations away from high wolf-use areas while wolves are centered around their denning areas at lower elevations in the early summer period; however, it could equally be attributed to the drought conditions of the past several years. Dry climatic conditions have left relatively little forage at the lower elevations, possibly pushing elk to the cooler, moister ridgetops.

A preliminary population reconstruction effort for the northern Yellowstone elk herd resulted in minimum number alive (MNA) estimates of 10,856 elk in 1995, 10,625 elk in 1996, 8,280 elk in 1997, 7,228 elk in 1998, 5,676 elk in 1999, and 4,245 elk in 2000. The decline in these MNA estimates over time does not represent a decline in the elk population. There is simply a smaller sample of elk mortality data used for population reconstruction in years closer to the present (these numbers become more accurate with each additional year of elk mortality data).

We recommend that the NPS continue to gather data on elk mortalities caused by hunting, cougars, wolves and winterkill. Both the MNA estimates and sex–age composition of the northern herd will become more robust with each additional year of population reconstruction data.

Project title: Willow Persistence in Yellowstone National Park: Interactive Effects of Climate, Hydrology and Herbivory

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Objective: The focus of our study is to tease apart the influences of hydrology and herbivory on the growth and reproduction of willows (*Salix* spp.) on the northern range of YNP. Willows have declined in the northern range over the last 100 years (Houston 1982), and potential driving factors include a recent increase in elk (*Cervus elaphus*) and a decline in water tables (due to a decline in beaver [*Castor Canadensis*] and/or a drying climate).

One approach we will use is a field experiment with two treatments: herbivory reduction (by exclosing large herbivores) and water table elevation (by inhibiting the velocity of small adjacent streams). The experiment is fully factorial, meaning that each site consists of four plots: an exclosed and water-elevated plot, an unexclosed and water-elevated plot, an exclosed and water-normal plot, and a control plot. We are replicating this design four times at the site level in order to obtain enough statistical power to determine the relative influences of the treatments and any potential interactions. We will measure the response of three willow species (*S. geyeriana*, *S. bebbiana*, and *S. boothii*) by measuring current annual growth, plant height and volume, seed production, water stress (by measuring xylem water potentials), and groundwater utilization (by comparing isotopic signatures of groundwater vs. xylem water).

Secondly, we will conduct a study of willow ages and ring widths in order to address willow establishment and to expand the temporal and spatial scope of the study. Comparison of willow ages and ring widths with elk population data, climate data, and historical records of beaver ponding will allow an analysis of the relative importance of herbivory, climate, and beaver presence to willow growth and establishment over the past 50–100 years. Aging of willows will take place in areas of documented beaver damming (Jonas 1955) and will allow us to determine if the timing of willow establishment coincides more closely with damming or with periods of reduced elk (Warren 1926). We will also examine growth patterns of willows in areas where beaver ponds have likely not been historically present (i.e., groundwater discharge zones and large streams) to differentiate the effects of climate and elk population on willows growing in other hydrologic environments.

Because beavers may be instrumental to willow survival and their historic presence in the Park prior to the 1800s is not well documented, we will conduct two studies to determine their historic presence in the Park. First, we will examine stratigraphic cross-sections of stream floodplains to date beaver pond deposits. An initial date from a probable pond deposit on Elk Creek, 1.7 m below current floodplain level, yielded a calendar date of 1010 AD (Beta #161788). Pond deposits will be identified using sediment grain size analysis. Secondly, in order to extend the spatial extent of the study (since streams migrate and beaver don't always build dams in the same spot) we will conduct a dendrochronological study of floodplain conifers to look for evidence of ponding in the ring record. Calibration of the trees' sensitivity to ponding will be done by selecting a set of trees that are various distances from known historic beaver pond margins (Warren 1926). These tree rings associated with stream flow conditions will be compared to long-term regional tree ring series to look for correlations with climatic patterns.

Findings: 2002 was our second field season and our first year of collecting post-treatment data in our field experiment. Our velocity inhibitors were successful in raising water tables; mean August water table depths in treated plots were 42 cm higher in 2002 than in 2001, while untreated plots were only an average of 7 cm higher. We conducted an analysis of variance on growth with pre-treatment data as a covariate, and found that damming had a positive effect on current annual growth for *S. geyeriana*, while exclosing had a negative effect on growth for both *S. geyeriana* and *S. bebbiana*. The plots with the largest increases in *S. geyeriana* biomass were the dammed, unexclosed plots, suggesting that added water increases the ability of browsed plants to add new biomass. Plants within exclosures, on the other hand, expended more energy on reproduction; both catkin production for all three species and seed rain were higher inside exclosures. Interestingly, there were no significant differences in any species in total plant height at the end of the 2002 growing season; apparently, the increased growth of the unexclosed plants (along with a growth form of fewer, longer shoots) was enough to compensate for their lack of protection, at least for the first year.

Analyses relating plant water stress to an interpolated water table surface are currently in progress, as is lab work to determine the water sources of willows using isotopic techniques. We have found that our ground water samples are isotopically distinct from rainwater samples, so we are hopeful that we will be able to use this technique to resolve the relative importance of soil water vs. ground water for plants in our study sites.

Preliminary results of willow establishment ages are not correlated with the hypothesized climate and beaver-induced hydrologic changes that occurred during the twentieth century. There has been relatively continuous willow establishment at our study sites over the past 80 years, and there are a large number of willows that established in the 1920–30s, a climatically diverse period that had large beaver populations in the northern range. Further spatial and statistical analysis will determine if this correlation between beaver abandonment and willow establishment in the 1920–30s is significant. Interestingly, a significant number of willows established in 1989, following the fires of 1988. Elk creek, whose floodplain actively burned, has the majority of the 1989 willow cohort. These plants established at heights close to the active channel and up to 2 m above it. There is no indication that the 2 m high upper terrace experienced any hydrologic event that would have created a suitable establishment regime for the 1989 cohort. The elevation range of establishment along with spatial and temporal correlation to the fire, suggests that the burned floodplain, or slope transport of sediment from burned areas, were disturbances that facilitated willow establishment the following spring.

The establishment ages indicate that between the 1920s and 1989 there was low, but continuous willow recruitment at most sites. This time span of slow but steady recruitment does not appear to be associated with hydrologic events or other specific disturbances, such as fire. After ~1970, most willows established <1 m above the current channel, with the exception of the 1989 cohort, which established across a wide range of heights. This may be evidence for a period of downcutting, initiating around 1970, because willows that established prior to 1970 are between 0 and 2.5 m above the current channel and most willows established since 1970 are <1 m above the current channel.

Project title: A Pilot Study on the Relative Abundance and Distribution of Snowshoe Hares in Yellowstone National Park

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Objective: Snowshoe hares (*Lepus americanus*) are important forest herbivores and are by far the dominant prey for the federally threatened Canada lynx (*Lynx canadensis*). When we began, the distribution and abundance of snowshoe hares in Yellowstone National Park were unknown, but lynx had recently been confirmed in YNP. Our major goals were to initiate a broad-scale survey for snowshoe hares across the park and within the major forest types, and to relate snowshoe hare abundance to habitat features (e.g., stand density, understory cover). Our secondary goal was to survey for red squirrels (*Tamiasciuris hudsonicus*), which are an important supplementary prey type for lynx.

Findings: We established 13 study grids in 4 forested habitat types characteristic of Yellowstone, spruce-fir, lodgepole class 2 (LP2), lodgepole class 3 (LP3), and 1988 burn. We chose these sites either because they were thought to be likely lynx habitat (spruce–fir, LP3), or because they are a dominant stand type within YNP forests (LP2, 1988 burn). We spread our sites throughout the park. With the exception of Frank Island, sites were paired; sites within pairs were less than five miles apart, while distances between pairs were 20–60 miles apart.

On each study grid, we live-trapped hares for three to five nights to obtain mark-recapture estimates of snowshoe hares. We counted fecal pellets on 80 small plots per trapping site as an additional index of snowshoe hare abundance. We also conducted fecal pellet counts on 28 additional sites scattered throughout the park. These sites were also in our four major habitat types and sites were chosen to extend our spatial coverage within the park. We conducted surveys looking for red squirrel middens (an index of squirrel abundance) on all of the study grids.

Preliminary results: Our trapping yielded snowshoe hares on only 4 sites out of 13. The two top sites were a 1988 burn site near the Firehole River (the 3 other 1988 burn sites had no hares) and an LP2 site near the south entrance (2 other LP2 sites had no hares). Our two mainland spruce–fir sites had one and two hares; Frank Island is also spruce–fir and had no hares. We caught no hares on our 3 LP3 sites. These results are echoed by the fecal pellet counts on these areas. The extended pellet surveys across the park showed low snowshoe hare densities in all four habitat types, again with spruce-fir and dense LP0 producing higher densities than LP2 and LP3. Red squirrels were most abundant in the most mature stands, i.e., spruce–fir and LP3.

Preliminary conclusions: These hare numbers are very low. We have extensive hare trapping experience in Yukon and western Montana, and these Yellowstone numbers are at the bottom end. During summer 2002, using identical methods and numbers of sites, we captured >275 hares in Flathead National Forest in western Montana. On the basis of this early comparison, it appears that the open lodgepole forests of Yellowstone are marginal habitat for snowshoe hares. We have vegetation data (primarily on habitat structure) for all of our sites, and we will be analyzing these data more fully to see the attributes of the sites that did support hares.

Intended work: During the 2003 field season, we will extend these surveys. Our goals are to expand our spatial coverage as well as resampling in the same areas to see if there are temporal patterns in hare and squirrel distribution or abundance.

Project title: Sagebrush Ecology and Ungulate Relationships

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Objective: (1) To determine the current status of the sagebrush-shrub community on the northern YS mule deer winter range; (2) determine the importance of the sagebrush-shrub community to wintering mule deer and elk; (3) describe the effect of man-caused and natural fire, including interactions with browsing, on sagebrush ecology on the northern Yellowstone winter range; (4) determine what management techniques can be implemented to preserve or enhance mule deer and elk habitats associated with sagebrush–shrub communities.

Findings: Mule deer utilize the several sagebrush habitat types in the boundary line area as key wintering types. They use the four woody sagebrush and three rabbitbrush heavily as browse, although they display a decided preference among taxa on winter range. None of the sagebrush have re-established. Significant differences were found in the development of protected and browsed shrubs following the 1988 fire. After fire big sagebrush cover at five sites averaged 20% with protection and 9.7% were browsed. Sprouting shrubs generally responded in the same manner.

Project title: Causes for Habitat Selection of Uinta Ground Squirrel

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Objective: To determine if populations of Uinta ground squirrels (*Spermophilus armatus*) inhabiting open grasslands demonstrate variation in behavioral patterns, natural stress hormone levels and demography to populations that inhabit adjoining shrubland habitats as a result of a heightened perception of fear of predation. This fear stems from the obstructive properties caused by the shrubs as the animal attempts to scan the horizon in search of predators. Ground squirrels are highly dependent on vision for predator avoidance. Because the Uinta ground squirrel is an important prey item for many species of predators including coyotes, badgers, weasels, and several raptors and experience a high degree of predation pressure, they are likely to be affected by the loss in scanning ability caused by the shrubs. One response may be to reduce foraging time in favor of more vigilance behavior. Increases in vigilance can lead to increased stress levels and possibly affect the animal's relative health and survival probability. Through this study we seek to better understand how fear of predation can impact this species habitat selection and how inhabiting one habitat over the other can lead to changes in individual behavior and stress hormone level. Understanding these factors is important as we try to manage our rangelands and understand the impact of habitat change.

Findings: The data are currently being analyzed. Preliminary results indicate that vigilance behavior is effected by vegetative structure. More occluded habitats caused increases in predator wariness. Population densities did not seem to be affected by the presence of shrubs. Small sample sizes for some grouping variables may indicate a need for some additional data collection in the field this upcoming summer.

Project title: Browsing Phenalogy of Willows, Cottonwoods and Aspen on the Northern Range, Yellowstone National Park

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Objective: The objectives of this study are to determine when the woody riparian species are browsed during the winter and to determine if it occurs as a short-term episode or as a continuous process during the course of the winter. This information will be correlated with climate to look for climate-browsing interactions. We are recording only the cumulative percent of stem tips browsed and not the percent of current annual growth taken.

Findings: The time of browsing has followed the pattern exhibited the previous years of the study. Early in the season there has been very light browsing, which we interpret as exploratory, followed by a short period of more intense browsing, terminated by a complete taking of at least the current year tips. This has occurred generally between late December and late January or late February. This year the cottonwoods at a site that had been lightly browsed earlier than before.

The timing of these events has varied geographically, between species and between years. At sites where both willows and aspen or willows and cottonwoods occur the willows have been eaten earlier than the other two species.

Project title: Geologic Controls on Ecology of the Greater Yellowstone Ecosystem, Particularly the Grassland–Forest Contrast

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Objective: The objectives are to document the relation between the ecologic distribution of plants and the surficial and bedrock geology of the Greater Yellowstone Area; to begin documenting the soil moisture distribution in grassland/forest contrast, and to test the hypothesis that the grassland/forest contrast is related to soil moisture distribution. This will be done through the following processes: (1) Compile and calculate the annual soil water distribution from existing data from 12 stations in the northern Greater Yellowstone Area that were monitored in the 1960s and 1970s. (2) Install TDR (time domain reflectometry) instrumented profiles each across the grassland/forest boundary will be used to follow soil moisture variation. (3) Document the relation between vegetation and geology based on the statistical relation between vegetation and surficial geologic and bedrock geologic maps, aided by ecologic and geologic knowledge accumulated over years of work (i.e., Despain 1990; Pierce 1979), including fire history, glacial source areas and flow directions, deposition of thin, more nutrient-rich loess, and rapid snowmelt driving the annual soil-moisture cycle. We will particularly focus on the distribution of grassland and forest and the geologic and other factors that control this difference

Findings: Information collected by the Soil Conservation Service was obtained and put into digital form and is available for analysis. Two transects have been instrumented with moisture sensors at four depths (where possible) in four soil pits in each transect. These sensors have successfully recorded soil moisture since November 9, 2001. The record interval during winter months was twice daily and during the summer was six times per day. Snowmelt and rain events were recorded in the surface layer and the wetting front was recorded as the moisture soaked into the profile. This year it was apparent that the forest soils began their wetting cycle later than the season by a week or two and the moisture in the middle of the profile was wetter in the forested soils. The recorders are being maintained and monitored.

Project title: The Biogeochemistry of Sublacustrine Geothermal Vents in Yellowstone Lake

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Objective: Yellowstone Lake, the largest, high altitude lake in North America, is situated within the Yellowstone Caldera, a terrestrial "hot spot" world renown for its geothermal features: numerous hydrothermal springs, geysers, mud pots, and fumaroles. Recent observations indicate that this geothermal activity is extensive within the lake basin itself, and that sublacustrine hydrothermal springs and gas fumaroles may have a significant impact on the biogeochemistry of this large, oligotrophic system. In a situation analogous to MOR hydrothermal systems and the Hawaiian seamounts, the reaction of water with minerals at elevated temperatures and pressures yields fluids with highly concentrated dissolved components up to two orders of magnitude greater than ambient lake water. The release of these anoxic, superheated hydrothermal solutions (>100°C) into cold well oxygenated bottom waters has produced environments unique in the limnology of large inland seas—highly enriched water column concentrations, complex microbial mats and unusually dense congregations of aquatic worms, sponges and zooplankton, and extensive mineral formations of hydrothermally deposited concretions, pipes and chimneys. The overall objectives of this research are to develop a better quantitative understanding of the impact of these geothermal features on the biogeochemistry and ecology of the lake.

Findings: Previously, with NOAA support, we had identified a host of interesting hydrothermal and geothermal features in the lake, including hot springs in small but deep canyons and craters at depths up to ~100 feet below the charted depth of the lake, widespread fumarole and underwater geyser activity, and a series of anomalous "spires" or chimneys some 20–30 feet in height. These formations consist almost entirely of amorphous silica, yet how these spires form, their age, and whether any are hydrothermally active—are all unknowns. In other parts of the basin, unexplored to date, park personnel report anomalous holes in the ice in winter, despite this being one of the coldest spots in North America.

Project title: Developing Effective Ecological Indicators for Watershed Analysis

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Objective: This study is designed to develop improved indicators and innovative techniques for assisting and monitoring ecological integrity at the watershed level in the western United States. Its specific objectives are to develop practical, scientifically valid indicators that (1) span multiple resource categories, (2) are relatively scale independent, (3) address different levels of biological organization, (4) can be rapidly and cost-effectively monitored by remote sensing, and (5) are sensitive to a broad range of anthropogenic and natural environmental stressors. The study, using tributaries of the Upper Yellowstone River and their watersheds as study areas, is based, in part, on the hypothesis that streams and riparian areas often reflect the ecological integrity of the associated watersheds. Due to a "funnel effect", these areas are the accumulation zones of environmental disturbances occurring in the watershed. Identification, assessment and validation of effective indicators will involve integration of results from research at various scales, including (1) analysis of hyperspectral and traditional multispectral imagery from both aerial and satellite platforms, (2) field surveys of stream morphology and riparian habitat, (3) analysis of remote sensing of stream and riparian attributes to assess indicators; and (4) intensive site-specific stream sampling of macroinvertebrate communities to validate the effectiveness of these indicators in assessing watershed condition. Use and evaluation of remote sensing technologies in conjunction with ground sampling is the primary research methodology. Selection of appropriate indicators will be influenced by their ability to be monitored by remote sensing. Research on indicators first requires an understanding of the processes and components that create the system from which indicators are selected. Only after this understanding can truly functional indicators be selected.

Findings: Forest fire is a vital ecological process capable of inducing complex fluvial response, but the integration of these effects across entire watersheds remains poorly understood. Using downstream cross-sectional and geomorphic data, acquired geographic information on land cover and forest fire, spatially explicit statistical analyses suggested that channels with a greater percentage of burned drainage area were associated with markedly higher cross-sectional stream power, relatively smaller width/depth ratios, and lower bank failure rates 12 to 13 years after the fires. These results implied that streams became more powerful in the aftermath of forest fire and that net incision had been the primary response in second- to fourth-order channels since the 1988 Yellowstone fires. The combination of elevated post-fire discharges and decreased sediment supply induces an episode of incision. Site-specific channel changes are highly variable because streams can accommodate post-fire increases in energy and sediment supply through multiple modes of adjustment.

Riparian vegetation studies based on site and patch analysis show that patch type distribution and dominant species at all canopy layers were basin-specific yet soil properties were homogenous. At the cross-section scale, little variability was detected in hydrogeomorphology, vegetation or soils across the

100-year floodplain using univariate analyses. Multivariate analyses of relationships between physical and biological properties in 2-, 5-, 10- and 100-year floodplains revealed basin-specific patterns. Riparian vegetation communities in Soda Butte and Cache showed greater responsiveness to fluvial processes and forms at each flood stage than Tom Miner outside YNP. Dominant variables influencing herbaceous vegetation varied from predominantly autogenic to allogenic in character. The responsiveness of herbaceous vegetation to the varying processes acting on small mountain floodplain environments lends itself to serve as a good indicator of floodplain-stream connectivity.

Analysis of macroinvertebrate, physical, and chemical data has been completed. Standard community metrics (i.e., richness, abundance, density, Simpson's dominance, and community biomass) are completed for all Cache Creek, Amphitheater, Upper Soda Butte, and Tom Miner sites and are beginning to be used to evaluate potential impacts relative to conditions found at pristine reference sites (Cache Creek sites) or upstream versus downstream of the entrance of an impacted tributary (Tom Miner complex).

In 2002, we made substantial progress on the remote sensing and spatial analysis aspects of this project. In brief, this progress fell into four major categories: (1) examination of the ability of hyperspectral imaging to identify stream geomorphic units in an unsupervised, computer automated approach; (2) analysis of the relationship of field collected geomorphic data to watershed condition; (3) collection of hyperspectral images for all streams within the study area and ground data for analysis of spectral responses of geomorphic units; and (4) detailed design for analysis of the relation between remotely sensed stream geomorphology and watershed condition. Effects of spatial, spectral, and radiometric resolution on remote mapping of fourth-order in-stream habitats were evaluated by comparing hyperspectral imagery to simulated multispectral data. Spectral resolution was more important than spatial or radiometric resolution in improving classification accuracies, although overall accuracies never exceeded 62%. Overall accuracies were significantly greater for (1) hyperspectral data (7.2%) compared to simulated multispectral imagery, (2) 1-m pixels (4.7%) compared to 2.5-m pixels, and (3) 11-bit data (0.8%) compared to 8-bit data. Higher spatial resolution also enabled removal of transitional areas between units by using interior buffers, improving accuracy by up to 15.6%.

Project title: Persistence of Aspen Seedlings Established After the 1988 Yellowstone Fires

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Objective: (1) Maintain previously constructed elk exclosures at three sites (annual inspection and repair); (2) measure height, basal diameter, density, recruitment, and mortality of post-1988 aspen seedlings within the exclosures to document long-term population trends and persistence/extirpation of post-1988 seedlings (collect measurements every 2–5 years for the next 5–15 years); (3) periodically measure height, basal diameter, density, recruitment, and mortality of post-1988 aspen seedlings in 23 small plots throughout the area burned in 1988 (plots are off trail, unfenced, and marked only with small rock cairns).

Findings: The exclosures at the three sites have been maintained continuously since 1996. At the low-elevation site (near West Entrance), many of the seedlings that established after 1988 are now >2 m tall, and appear likely to persist indefinitely, resulting in addition of new aspen clones to the Yellowstone population. These surviving aspen individuals are mostly found in dense tangles of fallen trees. At the two high-elevation sites (near Old Faithful and Lewis Lake), the aspen are persisting but not elongating, even with protection from elk browsing. Evidently the local micro-climate is not suitable for aspen. In unprotected sites throughout the park, post-fire aspen seedlings generally remain small (<1 m) and are gradually disappearing, except wherever (i) elevation is < 7,500 feet and (ii) plants are protected from elk browsing either by fallen trees or unstable slopes. In these latter locations, it appears that new genetic individuals have been added to the regional aspen population—a rare event that has not been previously documented.

Project title: Validation of High Resolution Hyperspectral Data for Stream and Riparian Habitat Analysis

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Objective: The objectives of this Hyperspectral EOCAP Project are twofold. First, the project seeks to test the application of airborne hyperspectral imagery to riparian and in-stream ecological and environmental studies and monitoring. Secondly, using experience gleaned from these application tests we are defining the unique and common requirements of hyperspectral data for operational commercial and scientific uses in the area of stream and habitat analysis. The results we are creating fall into these two broad categories: specific stream study application results and more general conclusions about commercial hyperspectral data requirements. We are documenting which specific stream ecology variables can best be measured from airborne hyperspectral sensors, and which stream parameters are not amenable to hyperspectral determination. Through acquisition of the field and airborne data, development of experimental protocols, analysis and processing of the hyperspectral data and documentation of the results we are building the case for stream and riparian studies using hyperspectral data. Furthermore we are discovering, often through the process of trial-and-error, numerous critical gaps and deficiencies that exist in current systems that hinder the commercialization of hyperspectral data for riparian studies.

Findings: In 2002, hyperspectral data sets collected in 1999–2000, 1 m, 5 m, and 8 m Probe-1 (128 channels) and 2 m and 17 m AVIRIS data (224 channels) were further groundtruthed and analyzed. During the summer and fall of 2002 we specifically collected ground data across the northern range of YNP to examine the spectral contribution of riparian species and condition. We measured canopy coverage of riparian species groups (willow, aspen, alder, cottonwood, and other) in order to understand and quantify the effects of species differences and species condition (age class, size class, and percent dead) on the spectral signal recorded by the sensor(s). Additional groundtruth data were collected along the Soda Butte and Cache Creek study sites. During the 2000–02 period, six main classes of ecological parameters were classified: (1) stream morphological units, (2) stream depth and flow regime, (3) substrate particle size, (4) in-stream algae chlorophyll levels, (5) woody debris, (6) heavy metals and associated mine tailings in fluvial sediments, and (7) riparian vegetation community mapping including individual species identification of willow, sedge, cottonwood, aspen, upland grasses, rushes, alder, sagebrush, and conifer species. These six main classes of variables span the range from relatively easy to extremely difficult, in terms of hyperspectral measurement. Each ecological variable has its own degree of hyperspectral leverage, or observability in the hyperspectral data. Furthermore, key issues such as spatial and spectral resolution, noise level, geometric fidelity, geopositioning accuracy and timeliness of data delivery and processing affect each specific application differently. Using a multiple spatial and spectral resolutions, and multitemporal data sets, we are investigating and documenting the complex interplay between instrument and data parameters and the usefulness and accuracy of the derived ecological products. While spectral contrasts exist among classes and species of vegetation, and even exist among subclasses of a single type, they are subtle and change throughout the growing season. Unlike the small spatial scale and rapidly time-varying nature of the in-stream parameters, the riparian vegetation is distributed in broader units that generally persist from one season to the next. Successful mapping of these plant species rests heavily on correlation of field spectrometry with airborne data. This particular application lends itself to a multi-temporal approach, leveraging the different spectral trajectories of the plant communities throughout the growing season. Initial investigations of the airborne data show tremendous spectral diversity in the riparian vegetation. Empirical spectral analysis indicates that more than a dozen spectrally unique vegetation classes can be mapped. Current efforts involve matching field mapping with the aircraft data results. Throughout our EOCAP project we are focusing on our dual hyperspectral objectives: developing convincing case study demonstrations of the hyperspectral measurement of important stream and riparian ecology parameters and documenting and developing the common and unique requirements of operational systems to perform these studies in the future. Specifically, we are collecting a laundry list of needs and requirements for commercial systems for hyperspectral stream studies. This list documents specific spatial, spectral, and radiometric design requirements. In addition we are addressing the more mundane, yet critical, aspects of operational acquisition and application including the timely delivery of data and products and its long-term use and archiving. Our results have been distributed in the form of a final report to NASA and five peer-reviewed publications with two more planned to submit in 2003.

Project title: The Ecology of Arbuscular Mycorrhizae in Yellowstone's Thermal Areas

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Objective: The arbuscular mycorrhizal (AM) symbiosis is an ancient interaction between plants and fungi (Remy et al. 1994, Redecker et al. 2000), occurring in most families of angiosperms, gymnosperms, bryophytes, and pteridophytes (Smith and Read 1997). AM fungi are obligate biotrophs: their spores can germinate without a host plant, but hyphal growth and branching pattern depend on plant root exudates (Becard and Fortin 1988, Giovannetti et al. 1993). The fungus colonizes the apoplastic spaces of root cortical tissue, and extends outside the root through the soil matrix. The host plant provides carbon for the fungus, while the fungus increases uptake of P and N (Johansen et al. 1993, Smith and Read 1997, Subramanian and Charest 1999), increases water acquisition (Stahl et al. 1998), and provides protection from pathogens (Newsham et al. 1995), potentially increasing host plant fitness (Heppell et al. 1998, Stanley et al. 1993).

The role of AM in YNP's thermal areas has not been studied and is difficult to predict across existing environmental gradients. Thermal sites are characterized by basic to acidic soils, elevated rooting zone temperatures (up to 57°C), low phosphorous levels, and potentially toxic concentrations of multiple elements. The sparse vegetation around the thermal areas is of small stature and has shallow rooting systems due to increasing soil temperatures with depth (Stout et al. 1997). While mycorrhizae augment plant growth in a broad range of environments for numerous host and endosymbiont species, they have also been shown to decrease growth in situations where the cost of carbon allocation to the fungus exceeds the benefits of the symbiosis (Johnson et al. 1997). This is particularly true in soils with high P availability, for plants with low P requirements due to slow growth, or in environments with other limiting nutrients (Koide 1991).

In thermal environments, where soil nutrient levels are low and plant growth is slow, AM may result in a growth depression for the host plant, unless the cost of C allocation to the fungus is balanced by some other benefit: an increase in a limiting nutrient or nutrients, or increased host plant tolerance to or avoidance of adverse soil conditions. The overall goals for this research are: (1) to measure the effects of AM on plant growth in limiting environments; (2) to assess the mechanisms by which AM affect plant growth; (3) to determine whether AM fungi occurring in thermal sites are specifically adapted to those sites; and (4) to establish single species cultures of AM fungi from YNP thermal areas, for use in future experiments.

Findings: This past winter we conducted a greenhouse experiment that would address the question of arbuscular mycorrhizal (AM) effects on host plants under high stress conditions, and whether AM fungi from thermal soils were specifically adapted to thermal soil conditions. We grew three species native to thermal areas (*Dichanthelium lanuginosum*, *Agrostis scabra*, *Mimulus guttatus*) with four AM treatments (non-AM, non-thermal AM, alkaline thermal AM, acidic thermal AM) and three pH watering treatments (3.5, 6.5, 9.5). Plants were adversely affected by the 3.5 and 9.5 pH treatments, evidenced by reduced flowering. Plants watered with pH 9.5 solutions were smaller overall. AM from acidic and alkaline thermal areas differed in their effects on host plants; plants were larger when grown with AM fungi from acidic sites, but had higher tissue P concentrations when grown with alkaline AM fungi. And while plants grown with pH 3.5 treatment were larger when associated with acidic than alkaline AM fungi, AM fungi did not consistently benefit plants grown under a pH regime similar to their origin. Soil pH is only one potential limitation in thermal soils, and the symbionts may be more adapted to temperature gradients than pH gradients (my next greenhouse experiment will address this possibility).

Lastly, for some plant responses, acidic and alkaline AM resulted in opposite effects. The functional differences of AM fungi originating from acid vs. alkaline soils within the same thermal basin suggest that either multiple species or multiple ecotypes exist in close proximity to one another. Further research will elucidate whether different species or ecotypes are present, and reveal the implications of these differences for thermal plant communities.

We have been continuing our work to establish single species cultures of AM fungi native to YNP thermal soils. Soil samples were collected at nine thermal sites throughout the Rabbit Creek basin, within *Mimulus guttatus* populations that were flowering or senescing. Two soil samples were collected in the Firehole river area in dominantly *Dicanthelium lanuginosum* plant communities. Two approaches were used to assessing mycorrhizal spores from field soil: (1) mycorrhizal spores were extracted from field soils immediately after collection, and (2) trap cultures were set up using diluted field soil. With the trap cultures, spores are isolated after growing sudan grass in the field soils for four months. Sudan grass readily forms mycorrhizae, and after four months, AM fungi from field soils will sporulate. In both approaches, mycorrhizal spores are extracted and separated by similar morphology to serve as inoculum in establishing single morphotype cultures. The field soil extractions resulted in 36 cultures with mycorrhizal establishment. These cultures are now being bulked up to produce a larger quantity of a single species of spores for later greenhouse and molecular work. Currently, spores are also being extracted from trap cultures established July 2002. These trap cultures should produce viable spores, which form quickly and easily. The immediate extractions captured spores, which may have formed under conditions of plant senescing as well as temporal characteristics. According to Dr. Joseph Morton, INVAM curator, two of the dominant species present in these particular Yellowstone thermal soils are *Glomus mosseae* and *Acaulospora delicata*. Interestingly, *Acaulospora delicata* has only been reported in southern Arizona and Costa Rica.

Project title: The Effects of Environmental Variability on Grizzly Bear Habitat Use

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Objective: The overall design of this project is to utilize existing data, expertise and newly collected data from advanced technologies to evaluate the impact of anthropomorphic influences on grizzly bear habitat selection. Specifically, these anthropomorphic influences will include impact of motorized and non-motorized trails on grizzly bear habitat selection. This project will also look at the similarities and dissimilarities in delineating grizzly bear home ranges when collecting locational information with different technologies (i.e., GPS and VHF). To address those issues, the following objectives have been developed:

1) This objective will look at correlation between home range size, available habitat and anthropomorphic influences. The response variable for this objective is the delineated home range of each of the collared individuals. Initially road density will be calculated using a moving window analysis that results in giving each cell a road density value based on miles per square mile of roads. The major human developments and point source activities will be defined using current U.S. Forest Service Grizzly Bear Cumulative affects model definitions. Other explanatory variables will include topographic influences including slope, aspect and elevation; climatic influences including precipitation, minimum and maximum temperature and snow water equivalence. These additional explanatory variables will be used to isolate the effects of the primary explanatory variables.

2) This objective will compare each bear's GPS locations and road proximity to available locations within that bear's home range. The response variable for this objective will be the locations of the collared individuals. As in objective #1, I will use additional explanatory variables to assist in further explaining the derived correlations. I will test to see if the individual habitat selection is significantly different than random distribution of locations within the bear's home range. I will also evaluate the possibility of a difference between the effect of roads on habitat use by those bears that spend a majority of their time in Yellowstone National Park and those bears who spend a majority of their time outside Yellowstone National Park. In testing for the significance of the impact of open motorized roads and non-motorized trails, it would be ideal to have a treatment and control area where we would have control over the opening and closing of roads and trails as well as the intensity of use on these roads and trails. Since this is not the case, we will use an observational approach of collecting location information and looking at the effect of habitat selection and its correlation to distance from roads and trails. For this element of the project determining resource selection will be crucial in order to differentiate the effect of roads versus the effect of other covariates related to habitat selection including climate, elevation, vegetation type or various other anthropomorphic influences.

3) This objective will compare the utilities of the GPS technologies and the VHF technologies in delineating grizzly bear home ranges. The response variable for this objective will be the delineated grizzly bear home range and the explanatory variables will be the GPS and VHF locational data.

Findings: During the 2002 field season the Inter-Agency Grizzly Bear Study Team and the Wyoming Game and Fish instrumented nine bears for this project. Of the 9 grizzly bears collared, 5 were adult females, 4 were adult males and 1 was a sub-adult male. The first collar was deployed on June 19, 2002, and the last collar was deployed on October 6, 2002. These collars have a programmable duty cycle, which we programmed to attempt a location collection every 210 minutes. The collars will power down on November 15, 2001, and come back on April 15, 2002. The collars also have a remote release mechanism, which will automatically release the collar throughout the 2001 non-denning season. Collars will be collected and data downloaded by the researchers. Also during the 2002 field season we retrieved 8 collars that were programmed to release during the 2002 non-denning season. Of these 8 collars 5 were from males and 3 were from females. The retrieved GPS collars had a mean acquisition rate of 62.4% with a maximum acquisition rate of 83.7% and a minimum acquisition rate of 48.4%. The mean operational days of the retrieved collars was 214 days with a minimum operational days of 180 and a maximum number of operation days of 245. The mean number of successful locations was 965 with a minimum number of successful locations from one collar being 623 and the maximum number of successful locations from one collar being 1,445. In addition to GPS locations an attempt was made to locate and record locations of these bears using radio telemetry approximately every 10 days. In addition to the above activities we updated ancillary biophysical data sets, collected intensity of human use data, continued preliminary data analysis, and report findings on our GPS collar test. We will also be presenting some initial analysis results at the 2003 International Conference on Ecology and Transportation.

Project title: The Ecological Relationship Between a Rocky Mountain Threatened Species and a Great Plains Agricultural Pest

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Objective: 1) To determine where army cutworm moths (*Euxoa auxiliaris*) (ACMs) originate. Environmental influences on ACM populations, either natural (e.g., weather patterns) or man-caused (e.g., pesticides, habitat conversion), may affect ACM recruitment and the numbers of adults reaching high elevation sites where they are a critical food source for the threatened grizzly bear (*Ursus arctos horribilis*) in the Greater Yellowstone Ecosystem (GYE).

2) To determine if ACMs harbor agricultural pesticide residues in their tissues. Pesticide magnification in grizzly bears that forage heavily on ACMs may have detrimental physiological or developmental side effects.

3) To elucidate the scale at which weather influences ACM migration from Great Plains agricultural areas to ACM aggregation sites in the GYE.

4) To determine whether ACMs mate in high elevation sites prior to their return to agricultural areas. If ACMs do not interbreed and comprise geographically based subpopulations, unfavorable conditions in localized areas in the Great Plains may impact ACM numbers at high elevation ACM aggregation sites used by bears. If ACMs do interbreed and are a highly mixed population, unfavorable conditions in localized areas in the Great Plains may not impact ACM numbers in high elevation ACM aggregation sites used by bears.

Findings: To date, army cutworm moths (*Euxoa auxiliaris*) (ACMs) have been collected for genetic and reproductive analyses from a total of 11 high elevation sites, including nine sites in Wyoming, one site in Washington, and one site in New Mexico. ACMs have been collected from 39 low elevation sites in Montana, Wyoming, Nebraska, and South Dakota. The sampling effort comprises a 360-degree radius around the high elevation study areas.

ACMs were collected for pesticide residue analysis during the 1999 and 2001 field season. Analyses of these ACMs showed no biologically significant traces of pesticides in the ACMs. Genetic analyses on the ACMs are being performed in the Laboratory for Ecological and Evolutionary Genetics and the Genomics Center at the University of Nevada, Reno. Each of these several thousand ACMs is individually keyed out to species and then their DNA may be extracted. A DNA library was developed for the ACM. This library has been screened for unique genetic markers (i.e., microsatellite loci), and primers were developed to amplify these loci in polymerase chain reactions (PCRs).

Over two thousand ACMs have been keyed out to species and have had their DNA extracted. PCRs have been optimized for one microsatellite locus and are being optimized for others. Analysis of the genetic variability at the PCR-optimized locus has begun. Analyses of additional loci will begin after their PCR-optimization is complete. Analysis of the variability at these loci will determine the origins of ACMs and, hence, the scale at which environmental factors may influence ACM migration to the GYE.

Reproductive analyses of ACMs in combination with genetic analyses of microsatellite loci will determine whether ACMs interbreed in high elevations. To date, hundreds of female ACMs have been inspected to assess their reproductive status at the time of collection.

Project title: Specificity in Ectomycorrhizal Symbioses

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Objective: Determine effects of artificial defoliation, litter addition, and dwarf mistletoe infection on ectomycorrhizal symbioses in pine/fir/spruce systems.

Findings: (1) Artificial defoliation of pine in mixed pine spruce significantly effects the mycorrhizal associations of both trees; (2) this also affects nitrogen assimilation function of both trees; (3) litter addition causes loss of some dominant mycorrhizal fungal species, and proliferation of others; (4) despite very high infection levels on pine, dwarf mistletoe infection had no effect on mycorrhizae in pure pine; (5) but, when an alternate plant host (fir) was available, mycorrhizal infection was significantly affected.

Project title: A Landscape Approach to Aspen Restoration: Understanding the Role of Biophysical Setting in Aspen Community Dynamics

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Objective: The aim of this study was to test the hypothesis that aspen performance varies across the landscape with biophysical gradients (e.g., climate, topography, and soils). If the hypothesis holds, we expect to see aspen performance vary across gradients in climate, topography, and soils. Variability in biophysical setting is likely to be strongly related to differences in aspen's response to its environment. Within its distribution, aspen performance and its probability of persistence are likely to be highest in favorable settings. Specifically, we expect aspen growth rates and ANPP to be highest at lower elevations, in moist climates, and in areas with relatively long growing seasons and moderate temperatures. We examine the radial growth rates (from increment cores) and aboveground net primary productivity (ANPP) relative to climate, topography, and soils.

Findings: To test the hypothesis, we analyzed variation in aspen diameter increment and ANPP across gradients in climate, soils, and topography in the Greater Yellowstone Ecosystem (GYE). We visited 107 sites throughout the GYE (eight sites in the Yellowstone National Park's northern range) and collected 613 increment cores. Aspen growth rates were measured as the average annual increment over the most recent 20 years. ANPP was estimated for a stand using increment, biomass estimates, and density of aspen at the site. We are currently conducting analysis of the data. If our hypothesis were true, we would expect to see significant variation in aspen growth rates and primary productivity among samples from different locations along the biophysical gradient. Contrary to our expectations, a one-way analysis of variance test (ANOVA) indicated that aspen growth rates did not vary significantly between regions ($p = 0.15$). ANPP, however, did differ significantly among regions ($p < 0.001$). No single biophysical predictor variables explained more than 26% of the variation in the two aspen performance variables and the best multivariate model explained only 53%. One possible explanation for these results is that aspen in the GYE may not occur across the full range of its abiotic tolerances. The distribution of aspen may have been constricted by competition with conifer or occurrence of fire at lower and higher ends of its biophysical tolerance. In this case, aspen performance would be similar within the relatively narrow portion of its niche where it currently occurs.

Project title: Yellowstone Field Ecology

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Objective: The objective was to conduct a 10-day field course for upper level biology majors on the ecology and natural history of Yellowstone National Park.

Findings: Through daily field trips, non-destructive sampling, and discussions, we examined flora and fauna in diverse communities and adaptations to the extreme variety of habitats found in the park. Field activity included: (1) Quadrat sampling (non-destructive) to estimate differences in biodiversity and characteristic flora in four life zones; (2) surveys of mammalian and avian fauna; (3) casual surveys in unique habitats—Norris Gyser Basin, Dunraven Pass, Yellowstone River and Yellowstone Lake; (4) casual surveys of fire successional areas with park ecologist Roy Renkin.

Project title: An Analysis of the Relationship Between Species Composition and Ecosystem Function in Streams: Implications For Stream Bioassessment

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Objective: This is a proposed addition to our application for a permit renewal (for the project "Predictive modeling of benthic macroinvertebrate community composition in the streams of Yellowstone National Park").

The purpose of this study is three-fold. First, to determine whether stream classifications based on invertebrate species composition (which are used in predictive modeling approaches to bioassessment) scale to measures of ecosystem function. That is, are streams with similar community compositions similar with respect to ecosystem processes? Second, to determine whether deviations from the expected community composition (as determined using predictive modeling), resulting from anthropogenic impacts, are correlated with measurable changes in ecosystem processes. In other words, are streams with reduced biological integrity "impaired" with respect to ecosystem function? Essentially, all stream bioassessment methods make the implicit assumption that measured changes in community characteristics do reflect, if not actually cause, underlying changes in ecosystem function.

A third, and related issue, is the more general question of how changes in biodiversity may affect ecosystem processes. This is an important and growing area of research, with broad implications in conservation biology. To date, however, most studies have addressed the issue in fairly simple plant communities. This project provides an opportunity to look at how biodiversity may affect ecosystem functions, as stream classes with similar community compositions also have similar biodiversity, whether measured at the species level, or in terms of functional classifications (e.g., trophic level, functional feeding group, etc.). In addition, we will have the ability to compare streams across a gradient of impairment, to address directly the question of how biodiversity may affect the ecosystem level response of a system to disturbance.

The inclusion of YNP in this study is important for several reasons. First, Yellowstone in general has a wide variety of stream types, most of which are relatively pristine. More particularly, Yellowstone has a large number of pristine low gradient meadow streams, which are underrepresented in the rest of the study area. In addition, this study provides an opportunity to begin to assemble a comprehensive picture of how stream ecosystems in the nation's premier national park function.

Findings: Using data we collected during 2002 from streams both inside and outside the park, we have been able to demonstrate that macroinvertebrate species composition based stream classification does partition a substantial portion (55–65%) of the variability in leaf litter decomposition rates among streams. This is the first step in designing a predictive model for ecosystem process rates, which will allow us to include ecosystem processes in stream bioassessments.

In 2003, we expect to extend these results by expanding the study to include more streams, and also to examine whether a similar partitioning can be achieved for other ecosystem process rates such as primary production and nutrient retention. We will also begin using the predictive model for macroinvertebrate species composition we have developed for the GYE to begin assessing the biological integrity of streams throughout the region.

Project title: Building a Mechanistic Basis for Landscape Ecology of Ungulate Populations

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Objective: To determine how observations taken at small spatial and temporal scales can be translated into expected patterns at landscape and geographic scales, as well as to investigate the influence of spatial heterogeneity on individual movements/demography, and on the distribution and dynamics of elk populations. In 2002 we focused on meso-scale movement patterns and developing detailed forage biomass maps for the park. Additional work continued on foraging behavior.

Findings: We were in the midst of data collection last year with considerable effort going into vegetation sampling, elk radiotelemetry monitoring, and habitat modeling. Results are beginning to pour out of our research effort with five manuscripts prepared for publication. We have published a methods paper on statistical procedures for evaluating resource selection functions, and we have devised approaches for correcting biases that are obtained using GPS radiotelemetry. We have developed models to characterize elk habitat selection at four spatial scales and the results of this work are in press with *EcoScience*. Habitat models developed at the park-wide scale are substantially different than those developed at smaller scales, especially in winter. We have developed foraging models to evaluate the ecological consequences of changes in vigilence, and we have shown that multi-tasking during foraging can alter the predictions of optimal foraging theory. Preliminary movement models have been developed with some intriguing results that show how elk move away from aspen stands in the presence of wolves.

Project title: Effects of Fires on Ecology of Coyotes in Yellowstone National Park: Baseline Succeeding Wolf Recovery

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Objective: Document long-term effects of the 1988 fires on the population dynamics and behavioral ecology of coyotes. Document the long-term impacts of wolf restoration on coyote populations and coyote behavioral ecology, including effects on coyote prey abundance, and competitor species. Continue long-term monitoring of coyote populations by adherence to those objectives listed in previous reports and peer-reviewed publications, including: home range size, survival, mortality cause, den locations, dispersal, pack size, individual identification, social class, pack location, loss rate, litter size, vocalizations, scent-marking, predation on small mammals and ungulates (and neonates), interactions with other species including ungulates, interactions with scavengers at carcasses, and radio-tracking.

Findings: Twenty-two coyotes were radio-collared in 2003, with good representation across all age classes. Intensive radio-tracking of these coyotes has resulted in additional insight into demography, home ranges, and the continuing high mortality rates of coyotes in the Lamar Valley. With this newly tagged cohort we are well positioned for the first stage of Phase III (wolf establishment) of the coyote ecology project. Survival analysis of the Phase II (1995–2001) data disclosed that wolves are the primary cause of mortality in northern range coyotes, accounting for 71% of all coyote mortalities from 1995 through 2001. Coyote survival rates after wolf reintroduction were compared with an overall survival estimate from the same study area prior to gray wolf restoration. Mean annual survival for adult coyotes prior to gray wolf restoration (1989–1994) was 91%, compared to 67% during the post-wolf restoration period (1995–2002). In the post-wolf period, survival rates differed significantly between social classes, between seasons, and by physical condition. A significant and sustained population decline of coyotes has resulted from the effects of interference competition with wolves. Larger wolf pack size is correlated with increased coyote mortalities, and wolf killing of coyotes constitutes a highly significant additive component of coyote mortality. Coyote recruitment continued to be low, along with small pack sizes, and the population of coyotes in Lamar and Blacktail continued at its reduced level. An additional important finding from analysis of the Phase I and II data indicated that an increasing proportion of the coyote population on the northern range exists outside of the conventional pack structure, existing as solitary residents who cover large areas (equivalent to several home ranges), foraging and mating opportunistically.

Project title: Ecology of Red Fox and Their Coexistence with Coyotes

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Objective: Little is known about the red fox that inhabits the northern range of Yellowstone National Park (YNP). In fact, recent and ongoing research (Fuhrmann 1998; current YNP permitted research project) on morphological/genetic characteristics and habitat use indicates that it is either a glacial relict from the last ice age or possibly an insular hybrid. It is included in several projects of the Resource Management Plan (last revision 1998) of YNP. Since the reintroduction of the gray wolf in YNP in 1995, possible "top down" effects are a research priority in YNP. Competition between coyotes (*Canis latrans*) and red fox is intense usually resulting in death to red fox. Competition between wolves (*Canis lupus*) and coyotes was also predicted to be intense, but less so. Since reintroduction wolves have decreased coyote populations by half, and sightings of red fox may have increased. This study seeks to establish the baseline ecology of the red fox in the Lamar, Soda Butte, and Little America valleys of Yellowstone's northern range. This study will quantify fox spatial use patterns in relation to coyotes and wolves, dispersal, litter size, survival rates, factors of mortality, and activity patterns. These specific objectives can only be obtained with use of radio telemetry, which in turn, requires the capture and handling of individual red fox. Other objectives include foraging behavior and food habits, interaction with other carnivores, and analysis of habitat use patterns. Specifically, we aim to: (1) determine population density, home range size, recruitment, and mortality rates for red fox on Yellowstone's northern range; (2) determine habitat use, and the influence of changing prey abundance; and (3) determine the spatial relationship between sympatric red fox and coyotes in the Lamar Valley through radio-tracking and snow-tracking.

Findings: The distribution, morphology, habitat use, home range attributes, and population density of red fox was examined in the northern Yellowstone ecosystem via snow-tracking. In addition, seven adult red fox were radio-tagged in the Lamar Valley and tracked intensively to determine home range size, social group attributes, and spatial relationship with sympatric coyotes. Habitat use was evaluated by snow-tracking fox using GPS and GIS technologies, with continuation of the snow-tracking transects covered in 2002. This data has refined the understanding of habitat use and preference, as well as the habitat segregation from that preferred by coyotes. Foxes were distributed across the study area in a wide range of forest cover types. Results show that red fox prefer forested and forest-edge habitats. Foxes significantly selected habitats that were less than 25 meters from an ecotone (structural edge). They preferred mesic sedge meadows and spruce-fir habitats at low angle slopes with a wide range in aspect. Lower elevational populations on the northern range were less specific in their selection of habitats and foraged mostly in mesic meadows and sagebrush. Above 7,200 feet, foxes preferred spruce-fir forests and foraged in mesic meadows and in spruce-fir and old-aged lodgepole forests. The mountain red fox that inhabits northern Yellowstone should be classified as a forest carnivore and is quite possibly a new subspecies of mountain fox, indigenous to North America. Fieldwork continued in winter 2002–03 to re-survey transects covered in 1994 and 1995.

Project title: Landscape Use by Elk During Winter on Yellowstone's Northern Range

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Objective: The objectives of this study were to document winter patterns of landscape use by Yellowstone northern range elk, measure elk feeding activity (as indexed by number of feeding craters), quantify snowpack characteristics, and examine how these and other landscape and habitat features influence elk foraging locations.

Findings: We measured site and snowpack characteristics, elk (*Cervus elaphus*) feeding crater densities and morphometry, and elk numbers in the Lamar River Valley and the Blacktail Plateau on the northern range of YNP. We conducted the study over three winters, 1992–93 to 1994–95, but the main sampling effort occurred over four monthly sample periods in year one. Snow depth, snow water equivalent (SWE) and snow resistance to horizontal movement and vertical penetration all increased steadily over the winter. The mean (SD) feeding crater diameter and depth was 118 (37) cm and 34 (11) cm, respectively, and both were positively correlated with snow depth. The mean (SD) crater volume was 385 (321) l, and the mean (SD) mass of snow excavated from a crater was 82 (72) kg. Non-woody plants (grasses, sedges and forbs) were the primary browse item in 90% of the craters. The highest aerial elk counts were observed in early- to mid-January, and counts declined substantially and steadily after 29 January. At this time, mean snow depth was about 50 cm and mean SWE was about 12 cm. The mean number of new craters on a plot showed a significant, negative association with snow depth, SWE and booted-foot sinking depth. We used the sum of craters on a plot across all four sample periods as an index of winter long feeding activity. Elevation and habitat type were the best site characteristics for differentiating plots in regard to winter-long use. Summed craters were negatively associated with elevation, and the habitat type with the highest summed craters was tufted hairgrass/sedge. Only about 5% of plots that had craters had areal crater coverage in excess of 14%, with a maximum of 23% coverage, suggesting that snow disturbance associated with cratering activity may inhibit elk foraging. We are preparing manuscripts for publication and are also preparing for fieldwork starting November 2002. Fieldwork in the winter of 2002–03 consisted of measuring the full protocol at a subset of the traditional plots. The winter was quite aberrant with snow accumulating in mid January with rainfall in February. Full coverage of the traditional plots will commence the winter of 2003–04.

EXOTIC SPECIES

Project title: Food Web Impacts of Exotic New Zealand Mudsnails in Rivers in Yellowstone National Park

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Additional investigator: Mark Dybdahl

Objective: Estimate impact of exotic *Potamopyrgus antipodarum*, New Zealand mudsnails, on native invertebrates by examining response of native invertebrates to inter-annual population variation in mud snails. During summer 2002 we observed low densities of mudsnails in Firehole River, and we want to use this natural variability in snail abundance and biomass to estimate native invertebrate population response. We sample during July, August, and September when mudsnail densities are typically highest.

Findings: We sampled Firehole and Gibbon rivers during July, August, and September. We are processing these samples in the laboratory.

Project title: Gypsy Moth Detection Permit

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Objective: Trap any gypsy moths that enter Yellowstone National Park.

Findings: With all the gypsy moth traps in YNP we trapped one gypsy moth at Fishing Bridge commercial RV campground. This is the second year in a row we have trapped a gypsy moth in the same area.

Project title: The Invasiveness of the Exotic New Zealand Mud Snail in the Greater Yellowstone Ecosystem

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Objective: The New Zealand mudsnail (*Potamopyrgus antipodarum*) an exotic in western U.S. rivers, attains densities of 550,000 individuals/m^2 within the Greater Yellowstone Ecosystem, where it is the dominant benthic macroinvertebrate in several rivers. However, their impact as grazing herbivores on the community is unknown. In one spring, *Potamopyrgus* coexists with the narrowly endemic, grazing snail (*Pyrgulopsis robusta*) which may be affected by resource competition with *Potamopyrgus*. In experiments over two field seasons and two sites, we quantified (1) the impact of intra- and interspecific competition on snail growth using in-stream cages, (2) the effects on algal biomass and interaction strengths of *Potamopyrgus* and *Pyrgulopsis* on algal food resources, and (3) the correlation between ambient snail densities of the two species to look for evidence of competitive exclusion.

Findings: Surprisingly, algal biomass increased (2001) or remained constant (2002) with increasing densities of snails, regardless of species composition. In fact, intermediate snail grazing levels resulted in the highest standing stock of algae. Nevertheless, *Potamopyrgus* significantly limited growth of *Pyrgulopsis*. However, growth rates were faster in both snails when *Pyrgulopsis*, versus *Potamopyrgus*, was the competitor; thus *Pyrgulopsis* appeared to facilitate growth of the invasive snail and, in the field, a positive correlation in snail densities was present at one site, but an apparent negative correlation downstream. However, for both sites, interaction strengths were equally small for both snails, indicating that competitive effects could not be attributed to differences in resource acquisition, but effects on snail growth were stronger in the downstream site. These results suggest that grazing stimulated algal growth, perhaps due to local nutrient enrichment, and either this or resource partitioning may minimize the effects of exploitative competition. In addition, the presence of the native snail enhances the growth of *Potamopyrgus* and thus, enhances its invasion success.

Project title: Alpine Vegetation of Yellowstone National Park in a Mountain Goat Context

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Additional investigator: K. Aho

Objective: (1) Categorize vegetation of YNP alpine volcanics, and characterize the categories biologically (species, percent cover, richness) and environmentally (moisture, temperature, soil texture, pH, salinity, N, P, K, Mg, Ca, Na); (2) identify plant indicators of environmental factors (temperature, water, stability, nutrients) for characterizing alpine vegetation of Yellowstone and other Northern Rocky Mountain alpine vegetation (this work will contribute to estimating temperature and water conditions for the preceeding); (3) compare the vegetation of cliff faces on under two substrates (limestone and volcanic) and three moisture levels (heavy, light, and no spray); (4) attempt to measure impact of exotic goats on alpine vegetation.

Findings: (1) We have identified (classification and ordination methods) six vegetation types (and subtypes): ledge (1), talus (2), ridge (1), steep (1), turf (3), and late melt (4). Vegetation of the types is being characterized by species and functional group richness and cover. Environments will be charaterized by plant indicators (of soil water and soil temperature) and on-site measures of soil texture, soil nutrients and salinity.

(2) Soil data (especially temperature and moisture, but also texture, pH, conductivity, and nutrient contents) from three summers will be used to charaterize thirty-six sites on Mount Washburn (Lamar formation). Regressions (simple and multiple) will be used to identify species indicators of soil properties. Indicators will be used to estimate conditions on our Langford formation volcanics (NE Yellowstone) and tested on other Northern Rocky Mountain vegetation types.

(3) Cliff vegetation (including lichens, mosses, and vasculars) on six environments is being categorized by classification and ordination methods. We expect six types (2 substrate x 3 water levels), and will characterize them biologically (species and function group presence and cover) and environmentally.

(4) Preliminary study of historic air photos indicates that the sparsely vegetated areas on Mt. Wolverine have expanded since exotic mountain goats colonization. Inspection of the sparse areas suggests that all cover types (e.g., grass and forbs) have declined and that the amount of bare ground is increasing.

Project title: Weed Inventory for the Northern Range of Yellowstone

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Additional investigators: Richard Aspinall, Bruce Maxwell, Don Despain, Frank Dougher, Tad Weaver

Objective: The overall aim of the project (2001–2004) is to survey the occurrence of non-indigenous species (NIS) of plants within the northern elk winter range of Yellowstone National Park. From the field data we will create maps of observed NIS occurrence (presence and absence). The data will be analyzed to evaluate for correlations of NIS occurrence with disturbance (human activities) and environmental variables, using logistic regression and Bayes theorem models. The best models will be used to create probability maps of NIS occurrence in areas not sampled. Maps will have observed and predicted locations of non-indigenous species.

Transect data will be collected in 2001–2004, and additional data collected to test and improve the predictive models in 2003 and 2004. The probability maps will assist the weed managers in stratifying which areas to select for further inventory/survey work, or provide baseline information for monitoring studies. The study is not intended to estimate the extent of populations (density or ha infested).

Findings: The northern range covers an area of 152,785 ha, which is too large to look for non-indigenous species over the entirety, so in 2001 we focused on identifying which sampling methods provide the highest probability of locating even the rarest plant species. This objective was achieved through computer simulation and field sampling. We have adopted a stratified and adaptive sampling methodology that will maximize the ability to predict occurrence of the NIS and quantify the degree of uncertainty in our predictions.

In 2002, all data were collected directly into data dictionaries on GeoExplorer 3 units that contained fields for non-indigenous species, and associated parameters including infestation length and width parameters, density, percentage cover and spatial pattern type; plus, environmental fields including habitat type, dominant vegetation, aspect, slope, and additional fields required by North American Weed Mapping Association (NAWMA).

One hundred thirty-three transects were sampled in 2002. Transects were 2,000 m long and 10 m wide. The start position of transects was randomly stratified on roads and trails but all ended 2,000 m from any road/trail. Sixty-two non-indigenous species are listed on the Yellowstone Park priority list, all of these were targeted but only 23 of these species were recorded in the transects.

The data are now collated, preliminary analysis and logistic regression and Bayes modeling performed and some non-indigenous species probability maps generated. Six species had occurrences of more than 1% over the study area. *Phleum pratense* had an occurrence of 6.5%, *Bromus tectorum*, *Cirsium arvense*, and *Poa pratensis* had occurrences just over 2%, *Linaria dalmatica* and *Bromus inermis* had occurrences of 1.6 and 1.3% respectively all other species were less, generally considerably than 1%. All species showed a decrease in occurrence as distance from road and trail increased. Correlations with other environmental variables were established.

FIRE

Project title: How Do Disturbance-Generated Patterns Influence the Spatial Dynamics of Ecosystem Processes?

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Objective: Our study addresses the effects of fire-generated landscape patterns or variability in successional communities on ecosystem processes. Forest fire is a well-studied disturbance, yet little is known about the long-term implications of a fire-generated landscape mosaic for ecosystem processes. Our current work builds our long-term studies of the causes and consequences of fire in the Greater Yellowstone Ecosystem. Our studies following the 1988 Yellowstone fires demonstrated that succession was surprisingly more variable in space and time than even current theory would have suggested, and that initial spatial patterns of disturbance may persist to produce long-lasting changes in vegetation. Our focus now is on explaining the spatial and temporal patterns of succession and understanding how these patterns influence ecosystem function. The most interesting new questions revolve around the degree to which the spatial variation in postfire vegetation—in particular, the six orders of magnitude variation in pine sapling density, ranging from 0 to >500,000 saplings/ha—controls the spatial variability in ecosystem processes across the landscape.

Our current study in Yellowstone continues to focus primarily on areas burned in 1988 and is addressing the following questions:

Question 1–Effects of postfire tree density. Do the enormous differences in postfire tree density produce differences in carbon and nitrogen availability across the landscape? Or, is nutrient availability governed largely by broad-scale abiotic gradients (e.g., climate, substrate) and/or fine-scale heterogeneity in resources or the microbial community, such that nutrient variability is not sensitive to the spatial variation in plant community structure?

Question 2–Convergence in forest structure and function. Does the disturbance-created mosaic leave a persistent functional legacy? What mechanisms in vegetation development may contribute to convergence (or divergence) in ecosystem structure and function across the landscape as succession proceeds?

Question 3–Role of postfire coarse woody debris. How does the spatial pattern of coarse woody debris vary across the post-1988 landscape, and what is the importance of this variation for ecosystem function? Are patterns of coarse woody debris abundance related to both prefire stand structure and postfire sapling density?

Additional studies are being conducted in Grand Teton National Park in sites that burned during the summer of 2000. These fires provided new opportunities for studying the spatial and temporal variation in ecosystem processes soon after the disturbances and how these patterns develop and change through time. By comparing spatial and temporal heterogeneity in ecosystem processes in similar sites that burned in 1988, 1996, and 2000, we can determine whether the postfire patterns of tree saplings increase the spatial heterogeneity in process rates.

Our study will contribute to the ability to predict broad-scale patterns of ecosystem processes, understanding the variability within and among ecosystems, and the consequences of disturbance for ecosystem function. Our study also will contribute to understanding potential effects of fire in natural areas of the northern Rocky Mountains. Finally, our research will provide the first integrated study of spatial variability in postfire succession and the consequences of this variability for a variety of ecosystem processes across a large heterogeneous landscape.

Findings: During the summer of 2002, our field studies focused on questions associated with the ecological role of postfire coarse woody debris and with convergence or divergence in ecosystem structure and function through time.

We initiated studies of the influence of postfire coarse woody debris on soil nutrient dynamics and decomposition in three locations burned in the 1988 fires under the leadership of co-PI Dr. Daniel B. Tinker and postdoctoral associate Dr. Kristine Metzger. At each site, we collected soil samples from positions located under trees that have fallen since the 1988 fires, under wood that was down prior to the 1988 fires, and out in the open. In addition, decomposition studies were initiated by placing litterbags containing herbaceous litter or conifer litter in each of those positions. These decomposition studies will continue for two years, with half the bags retrieved during summer 2003 and the remainder during summer 2004; this study will form the basis of a MS thesis for Alysa Darcy, student at University of Wisconsin. The effect of coarse woody debris on nitrogen availability is being measured using one-year incubations of ion exchange resin placed in soil cores at each site during summer 2002. Cores will be removed during summer 2003, and an integrated measure of nitrate and ammonium production will be obtained for a yearly time step. Initial laboratory analyses of the summer 2002 samples are in progress at the University of Wisconsin–Madison.

To explain and predict variation in the rates of treefall and abundance of postfire coarse woody debris, extensive sampling was begun during summer 2002 to quantify downed wood throughout the area burned by the 1988 fires. This sampling will be continued during summer 2003, and the combination of the intensive process-based measurements with the broad-scale analysis of coarse woody debris these effects at landscape scales. This study will form the basis of a MS thesis for Heather Lyons, student at Colorado State University.

Variation in forest structure (especially stand density) with time-since-fire was studied by a doctoral student, Daniel Kashian, who completed his PhD in December 2002. During the summer of 2002, a number of Kashian's study sites were revisited to obtain measurements related to ecosystem function—in particular, soil samples for potential nitrogen availability and microbial community composition, and foliar samples to determine foliar nitrogen concentration. This work was lead by postdoctoral associate Dr. Erica Smithwick, and laboratory analyses are in progress.

Project title: Fire Effects Monitoring

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Additional investigators: Vicki Pecha, Becky Seifert

Objective: (1) Monitor the effects of prescribed and natural fires on Yellowstone's ecosystems; (2) provide information to evaluate whether fire management objectives are being met; (3) refine our ability to predict fire behavior and fire effects through applied research.

Findings: The Yellowstone Fire Effects Monitoring crew is part of the National Park Service's overall Prescribed Fire Program. We have many ongoing projects including monitoring long term effects of fire on vegetation and fuels, effects and effacacy of fireline explosives as a fireline construction method, modelling of fuels and fire behavior in early post-fire lodgepole pine forests, using satellite imagery to assess fire severity, and researching and creating a spatial database of known historical fires.

In Yellowstone our responsibilities include monitoring the long-term effects of wildland fire-use fires (prescribed natural fires), management ignited prescribed fires, and monitoring of other fire management activities. In 2002 the Yellowstone Fire Effects Crew: 1) re-read a set of Wildland Fire Use monitoring plots which burned in the last two seasons. We also rephotographed several Wildland Fire Use monitoring plots installed between 1977 and 1989. 2) We installed four Wildland Fire Use FMH plots, one of which burned. 3) Our Fire History project is mostly completed. Data on fire perimeters in the archive have been researched and collated into a single database. Historical large fire perimeters dating back to early in the century have been entered into a GIS. Smaller fires have also been plotted. This record is reliable back to about 1928 with sporadic records extending into the late 1800s.
4) In late May we hosted students from the University of Iowa and the University of Utah who helped us sample early post-fire lodgepole pine forests for fuels information. This data will provide inputs into fire behavior prediction software. 5) We issued the third annual newsletter of the NPS Fire Effects Monitoring Program, Rx Effects <www.nps.gov/yell/technical/fire/rxfx.htm>. 6) We also maintain a website describing our activities <www.nps.gov/yell/technical/fire/effects.htm>.

Project title: Study of the Effects of the 1988 Wildfires on Yellowstone Stream Ecosystems

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Objective: This project examines the processes of stream ecosystem recovery after a large-scale disturbance (fire), while also examining the cumulative effects of a natural disturbance on an entire watershed (Cache Creek). Changes were monitored in the chemical properties of water, physical habitat conditions, and in the structure of biotic communities, which included primary producers (algae) and secondary consumers (macroinvertebrates). These results also will be used in conjunction with data from the previous 13 years to determine mid-range effects of wildfire on stream ecosystem recovery. We also are examining the difference between natural and anthropogenic disturbances to stream ecosystems by comparing stream ecosystem recovery after the 1988 fires in YNP with stream ecosystem recovery after anthropogenic disturbances such as logging and livestock grazing in stream watersheds outside Yellowstone National Park's northern boundary in Montana.

Findings: In 2000–01, 15 sites were chosen in YNP and grouped into 7 sets of 3 streams each. Several stream segments doubled as an upstream or downstream segment in the groupings. The 7 groupings were all located in YNP; 4 were on Cache Creek and 3 were on Soda Butte Creek. The Cache sets were: (1) High Cache 2nd order (upstream segment, unburned), Thunderer Fork (tributary, burned), and Middle Cache Creek 3rd order (downstream segment, burned) sampled August 2001; (2) Middle Cache 3rd order (upstream segment, same as downstream segment in grouping 1), Needles Creek (tributary, burned), and Cache Creek 3rd order (downstream segment, burned) sampled August 2001; (3) Upper South Fork Cache Creek (upstream segment, burned), South Fork of South Fork Cache Creek (tributary, unburned), and S. Fk. Cache Creek (downstream segment, burned) sampled August 2001; and (4) Cache Creek 3rd order (upstream segment, same as Cache Creek downstream segment in grouping 2), S. Fk. Cache Creek (tributary, same as S. Fk. Cache Creek downstream segment in grouping 3), and Cache Creek 4th order (downstream segment, burned) sampled August 2000 and 2001. Cache Creek 4th order (burned) near the confluence with the Lamar River was sampled August 2001. In 2002, these sites were augmented with a reconnaissance of the Lamar River upstream of Cache Creek and sampling of one site near the Lamar headwaters. The remaining sets, all on Soda Butte Creek were: (5) above, in, and below Amphitheater Creek (unburned, sampled 2000 and 2001); (6) Soda Butte Creek above Pebble (upstream segment, same as Soda Butte below Amphitheater), Upper Pebble Creek (tributary, unburned, sampled 2000), and Soda Butte below Pebble (unburned, sampled 2000 and 2001); and (7) Soda Butte Creek above, in, and below Lower Pebble (campground influence, sampled 2001). In addition, 13 stream segments were sampled outside YNP's northwestern boundary (Montana), they were arranged into four groupings of three to four stream segments. They include: (1) Mill and Colley (tributary, disturbed by logging) Creeks sampled August 2000; (2) Tom Miner and Horse (tributary, grazed by livestock) Creeks sampled August 2000; (3) Big Creek and Hyalite Creeks sampled August 2000; and (4) Mill (furthest downstream segment, impacted by livestock grazing) and Lion (tributary, impacted by fire and logging) Creeks sampled August 2001.

Macroinvertebrate samples have been completely processed for all Cache Creek, Amphitheater, Upper Soda Butte, and Tom Miner sites. Samples have been sorted but macroinvertebrate identifications have been deferred for 2000 for the Mill Creek/Cooley complex, Big Creek/Hyalite complex, Pebble Creek/Lower Soda Butte complex, and 2001 Pebble Creek/Soda Butte and Mill Creek/Lion complex, until relevance to the project is determined. Fieldwork in the Lamar watershed was completed August 2002 to determine applicability of our Cache Creek findings to other watersheds in the Lamar River basin. These samples will be processed in the next couple of months. Initial analysis of macroinvertebrate, physical, and chemical data has been completed and results were reported in 2002. Standard community metrics (i.e., richness, abundance, density, Simpson's dominance, and community biomass) are completed for all Cache Creek, Amphitheater, Upper Soda Butte, and Tom Miner sites and are being used to evaluate potential impacts relative to conditions found at pristine reference sites (Cache Creek sites) or upstream versus downstream of the entrance of an impacted tributary (Tom Miner complex). We currently are analyzing our macroinvertebrate data using multimetric techniques (principal components analysis and canonical correlation analysis) to evaluate correspondence with watershed and stream/riparian corridor measures. We also are examining macroinvertebrate functional feeding groups and possible indicator taxa or metrics for their ability to detect local- and watershed-scale conditions.

Project title: Mapping Horizontal and Vertical Distribution of Fuel by Fusing High-Resolution Hyperspectral and Polarimetric SAR Data

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Objective: The primary objective of this study is to fuse hyperspectral (and optical data such as ASTER) with polarimetric synthetic aperature radar (SAR) data to provide maps of the vertical and horizontal distribution of fire fuels by plant community or cover type. This is critical information not currently available from today's fuel mapping methods. Current fuel maps have limited use for predicting fire behavior, analyzing fire hazard, or developing fuel management strategies. A cost-effective, yet accurate method is needed for landscape to regional scales. The fusion of the aforementioned data types has complementary strengths, enabling the creation of high-resolution maps describing the vertical and horizontal distribution of fuels by cover type or species groups.

Findings: This study is a three-year study funded by the Joint Fire Science Program out of Boise, Idaho. Work on this study began January 1, 2002, and has included a great deal of effort during the first year. Major achievements include significant planning sessions and group meetings, clarification of the first year study site and a very successful first-year field season, significant database development and calculation of field data, assembling and assessing the utility of existing remote sensing data, planning for collection of both hyperspectral and SAR data, and development of image analysis and data fusion algorithms and approaches. We are currently continuing data analysis from the first field season, optimizing calculations to retrieve fuel parameters from field data, developing methods for image analysis and data fusion, and planning for a second successful field season. Our fieldwork will begin in late May 2003 and will require the same protocol to be conducted on the northern range sites located near Lamar Valley and additional sites near Canyon and Old Faithful. We will also require the limited destructive sampling of vegetation according the protocol and procedures developed for the summer 2002 field sampling.

Project title: The Status of Whitebark Pine Regeneration in the Greater Yellowstone Area Following the 1988 Fires: Burned vs. Unburned Forests and Mesic vs. Xeric Conditions; Assessment of Blister Rust Infection in Seedlings

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Objective: In 1990, permanent plots were established at subalpine elevations and studied until 1995 to follow the regeneration of whitebark pine communities after the 1988 fires. Plots were again measured in 2001. Our goals for 2002–05 were to compare regeneration densities for two ecological conditions (xeric, stand-replacing fire; mesic, stand-replacing fire), as well as compare understory changes in composition and cover, and seedling survival with respect to (1) differences in spring snow accumulation, (2) soil water availability, and 3) changes in soil water availability throughout summer. In addition, we proposed to examine whitebark pine in nearby unburned stands for prevalence of white pine blister rust.

Findings: The study is in progress. In spring and summer 2002, we obtained some measurements in each study area for snow depth, and data for all plots on soil water availability intermittently throughout the summer. We also obtained data on soil moisture and temperature throughout the summer for each study area. We examined four nearby unburned stands for white pine blister rust. To date we have found longer-lying snow accumulation and thus later melt-out, as well as higher soil water availability on the mesic, burned treatment which also supports the highest densities of both whitebark pine and other conifers. We found white pine blister rust present, but at low level, in nearly all stands examined on Mt. Washburn. As of May 2003, we should have data enabling us to do a plot by plot comparison of snow depth, melt out date, soil moisture, and regeneration densities.

Project title: Fire: A Force for Change and Regeneration in a Natural Ecosystem

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Objective: To study long term change in revegetation in areas affected by different fire intensities.

Findings: Study of revegetation and changes in composition of vegetation continued for year 15 post-fire in areas affected by the fires of 1988. Growth rates and reproduction in lodgepole pine seedlings/saplings were studied in 15 selected areas of the park that were affected by differing fire intensities. Growth of lodgepole pine in areas with high pre-fire serotiny and subjected to high fire intensity continues to be very rapid. Competition between individuals in dense stands appears to be minimal to date, and density has been maintained. Percent saplings initiating reproduction continues to increase at most sites. Yearly and three-year comparative photos are continuing at selected sites, and year-to-year changes in size and density of lodgepole pine have been documented by photographs since year 2 post-fire. Work was also initiated in September in areas affected by the 2003 East Complex fire along the east entrance road. Photo locations were established at 9 sites 2 weeks post-fire, from Sedge Bay to Sylvan Lake. Photo sites also were established at the Nine-mile trailhead and along the burned area of the Thorofare trail to the perimeter of the burn, approximately 1 mile along the trail. Revegetation patterns in this new burn will be studied in the same manner as for the 1988 fires. The East fire complex will be especially interesting ecologically because much of the area burned consisted of old growth spruce-fire forest (SF-2 and SF-3), in contrast to many of the areas affected by the 1988 fires. Vigorous re-sprouting of grasses was already occurring in wet meadows and along small watercourses 2 weeks post-fire. Photographic records of the revegetation (up to 15 years post-fire) of areas affected by the 1988 fires were supplied to Paul Picard, Collaborative for Advanced Landscape Planning (University of British Columbia) for conversion to digital images for a study on the public perceptions of the visual impacts of fires at the landscape level.

FISHERIES

Project title: Snake River Native Salmonid Assessment

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Objective: Native resident salmonid populations are in decline throughout much of their range, including the Upper Snake River Basin. This is a multi-phased project, funded by a contract to Idaho Department of Fish and Game from the Bonneville Power Administration, with an overall goal of protecting and restoring populations of native salmonids in the Upper Snake River Basin in Idaho to self-sustaining, harvestable levels. The first phase of the project is to assess the current distribution and abundance of existing populations of native salmonids throughout the Upper Snake River Basin, and to assess what factors influence this status. Toward this end, and to avoid omitting portions of a number of drainages that extend across state boundaries, we are attempting to survey native salmonids beyond the Idaho border, including in Nevada, Utah, Wyoming, and in Yellowstone National Park.

In 2002, we surveyed a number of subbasins in eastern Idaho, including the Henry's Fork of the Snake River, a small portion of which occurs in Yellowstone National Park. Because native salmonids, namely Yellowstone cutthroat trout, have been extirpated from most of the Henry's Fork subbasin, we did not select sites randomly as we have for other Upper Snake River subbasins, but instead we focused our efforts as much as possible on areas that have not been previously sampled and where cutthroat trout might still occur. We collected data from 87 sites throughout the Henry's Fork drainage, of which seven were located within Yellowstone National Park (three in Idaho, four in Wyoming). Sites sampled included one site on Cascade Creek (UTM location 512119E and 4886621N), two sites on Little Robinson Creek (494293E and 4893490N for lower site, 494846E 4895898N for upper site), one site on Boundary Creek (495280E 4907579N), one site on Wyoming Creek (496271E 4888730N), and we sampled two unnamed tributaries of Boundary Creek (498192E and 4898177N for first tributary, 498767E 4897316N for second tributary). At each site, we measured a number of stream attributes, and inventoried fish with backpack electrofishers. Due to unseasonably late emergence and difficulty in capturing particularly small trout fry, here I report results only for trout >100 mm. Capture efforts were focused on trout species, but at each site where they occurred, non-game fish were captured, identified to species, and relative abundance was estimated.

Findings: Fish were captured at four of the seven study sites (57%) within the park, compared to 53 of 80 sites (66%) outside the park. Salmonids were captured in three of the seven park sites, but none contained Yellowstone cutthroat trout. In comparison, 49 of 80 sites outside the park contained salmonids, including 12 that contained Yellowstone cutthroat trout.

One of the park sites (an unnamed tributary of Boundary Creek) contained a hot spring upstream of the site, which elevated water temperature substantially, and thus was devoid of fish. The other unnamed tributary of Boundary Creek contained good populations of rainbow trout and mottled sculpin, but the stream was too large to obtain a population estimate. The Boundary Creek site, although not completely dry, contained only intermittent stagnant water and also was devoid of fish, although spotted frogs were present.

Wyoming Creek downstream of the park contained rainbow trout and a sculpin species (possibly Paiute sculpin), but at the site within the park no fish were captured. Cascade Creek, a tributary of Falls River, contained a healthy population of rainbow trout (0.08 fish > 100 mm per m^2) as well as redside shiner and speckled dace. The two sites on Little Robinson Creek were only a few kilometers apart and not surprisingly contained similar fish populations, both for trout (0.21 and 0.17 brook trout per m? for lower and upper sites, respectively) and mottled sculpin (relatively abundant and both locations).

Overall status of Yellowstone cutthroat trout and native non-game fish species are currently being summarized for the entire Upper Snake River Basin in Idaho, as well as for the Henry's Fork subbasin. Stream attributes and other environmental factors that influence cutthroat trout distribution and abundance are also being analyzed for the roughly 850 sample sites across eastern Idaho. Detailed analysis of individual sites within Yellowstone National Park are not planned, but incorporating those sites within the overall analysis was deemed to be important to more fully sample the range of habitat characteristics found in stream environments across the historic range of Yellowstone cutthroat trout in and adjacent to Idaho.

Project title: Lehardy Rapids Yellowstone Cutthroat Egg Collection for the Development of Species Specific Brood Stock for Drainage Restoration

Principal investigator: Mr. James Barner
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Additional investigators: Loren Racich, Pete Feck

Objective: To collect and fertilize eggs for Yellowstone Cutthroat trout pairs to develop a captured brood stock program. Eggs are collected from the population, which inhabits the stretch of river from Yellowstone Lake to Upper Falls. Fish managment at Yellowstone have also asked for egg collection to aid in Whirling Disease research. The primary capture location will be Lehardy Rapids although other sites within the drainage may be considered if catch rates do not meet objectives. This brood stock will be used for drainage restoration of the endemic range of the Yellowstone River in Wyoming and also assist in the restoration projects in Montana.

Findings: Eggs were taken on four occasions (June 6, 13, 20, 27).
June 6, 2002:
Spawned 31 pair (13,340 eggs)
Water temp = 46 degrees
Air temp = 55 degrees

June 13, 2002:
Spawned 17 pair (9560 eggs)
Water temp = 44 degrees
Air temp = 56 degrees

June 20, 2002:
Spawned 31 pair (18,216 eggs)
Water temp = 48 deg
Air temp = 57 deg

June 27, 2002:
Spawned 24 pair (9614 eggs)
Water temp = 56 deg
Air temp = 70 deg.
All eggs were shipped to Tillett Isolation Hatchery in Lovell, Wyoming.

Project title: An Assessment of Tributary Potential for Wild Rainbow Trout Recruitment in Hebgen Reservoir, Montana

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Objective: (1) Estimate the relative contribution of redds and juveniles of each tributary to the total trout production of the Hebgen Reservoir system; (2) quantify spawning and rearing habitat, obtain temperature regime data, and conduct habitat limiting factor analysis for Hebgen Reservoir tributaries; (3) develop an index from a tributary (Duck Creek) known for high fry production to aid in the prediction of tributary potential for recruitment; (4) estimate the relative contribution of hatchery and wild rainbow trout and of wild age-0 and age-1 juveniles to adult recruitment; (5) evaluate the potential to enhance tributary spawning to increase the contribution of natural reproduction to the Hebgen Reservoir fishery.

The conversion from stocking to management of self-sustaining, wild trout populations has been a cornerstone of fisheries management in Montana rivers for the past 30 years. However, due to limited spawning habitat trout fisheries in Montana reservoirs remain almost entirely maintained by stocking hatchery fish. The presence of apparently high quality spawning tributaries in the Hebgen Reservoir basin prompted Montana Fish, Wildlife and Parks (FWP) to initiate a wild trout management program in 1979 for Hebgen Reservoir. The objective of this program was to establish a wild self-sustaining trout fishery. Wild rainbow trout Oncorhynchus mykiss have since established spawning runs in several tributaries and 100,000 wild fingerlings are stocked annually to bolster the fishery. However, catch rates of rainbow trout have shown a continual decline suggesting a lack of natural recruitment despite apparently high quality spawning habitat. The objective of this study is to assess reservoir potential for wild trout recruitment among tributaries and to identify potential limiting factors. Redd abundance will be used to assess current levels of spawning use in as many tributaries as possible. Potential factors limiting fry recruitment that will be measured include temperature, availability and quality of spawning and rearing habitat, and the presence of barriers. The number of spawning adults and outmigrating juveniles will be measured at Duck Creek, a tributary known to recruit high numbers of fry to Hebgen Reservoir, to determine relationships between the number of redds and the number of juvenile outmigrants. This study will provide management agencies with an assessment of local habitat conditions, habitat limitations and enhancement suggestions, as well as an evaluation of recruitment and potential for recruitment in Hebgen Reservoir. This study will also provide the framework for assessing potential for wild trout recruitment in other reservoir systems.

Findings: Redd surveys (spawning nest counts) were conducted on 11 Hebgen Reservoir tributaries. A total of 4,394 redds were counted during the 2002 field season. Duck Creek contained the highest number overall with 2,232 redds observed; approximately 51% of the basin total, and had a density of 81.5 per stream-km. Of the 2,232 redds identified in Duck Creek 229 were counted downstream of the Koelzer Pond, the remaining 2,003 were found in the upper Duck Creek drainage, primarily in Gneiss Creek, within Yellowstone National Park (YNP). The S.F. Madison River contained 845 redds and Black Sand Springs contributed 494 redds to the basin survey. Over 80% of the redds in the estimate were found in Black Sand Springs, Duck Creek and the S.F. Madison River.

An adult fish trap was operated to determine the abundance of upstream migrating rainbow trout and the average length of adult spawning females on Duck Creek. The trap was positioned approximately 350 meters downstream from the Yellowstone National Park boundary. The trap was installed on 1 April and was in operation until 19 June.

A total of 3,164 adult rainbow trout were captured at the Duck Creek trap. Females outnumbered males by a ratio of 3.8 to 1 (2,507 females to 657 males). The average length for the spawning females was 422.88 mm. The ratio of the number of redds constructed in the upper Duck Creek drainage (n = 2001) to the number of spawning females (n = 2507) was 1:1.25. The spawning migration peaked from mid-May to early June corresponding with stream temperatures of 8–10.5°C.

Attempts were made to enumerate outmigrant fry and to determine the timing of fry emigration with the use of downstream fry traps. Fry traps were installed at three locations on Duck Creek, including an upstream trap inside the YNP boundary, a trap at the downstream end of the Koelzer Pond, and a trap located upstream from the highway culvert. The traps were installed 20 June and were operated until 16 August. Together, the two upstream traps captured 26 fry throughout the fry-trapping period. In an attempt to locate fry, a visual survey was conducted in the upper Duck Creek drainage. The masses of fry observed earlier during redd surveys appeared to move into localized slow-water habitats in groups of 50 to 500. No substantial fry outmigration was documented during the 2002 field season.

Project title: The Spatial and Temporal Spawning Distributions of Yellowstone Cutthroat and Rainbow Trout in the Upper Yellowstone River Drainage

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Additional investigators: Bradley B. Shepard, James N. De Rito

Objective: Determine the amount of spatial and temporal isolation or overlap during spawning among Yellowstone cutthroat trout, rainbow trout, and hybrids of the two species; determine the effects of environmental variables, such as water temperature and water flow, on the spatial and temporal isolation or overlap observed; and determine spawning habitat use by Yellowstone cutthroat trout, rainbow trout, and hybrids among and within spawning areas in relation to spawning habitat availability.

Findings: See reporting year 2001 for initial findings for that year. During 2002, there were four radio-tagged fish that entered waterways of YNP. (Gardiner River: one rainbow and one hybrid, and Reese Creek: one hybrid and one cutthroat). All four of these fish were thought to have spawned in the waterways that they entered. This study is ongoing.

Project title: Cutthroat Trout Egg and Sperm Collection

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Additional investigator: Gary Bertellotti

Objective: To successfully manage Montana's Fishery resources we need to maintain our hatchery broodstocks with a wide genetic diversity. These broodstocks should mirror their wild ancestors as closely as possible. The original gametes for our Yellowstone Cutthroat trout broodstock came from McBride Lake in Yellowstone National Park in 1969. The last time gametes were taken from the lake to supplement the broodstock was 1987. To once again infuse our broodstock with new genetic material we want to again collect gametes from McBride Lake for three consecutive years beginning in 2001. Each year of the three-year program would require eggs and sperm be taken from the number of pairs of spawning fish needed to aquire 20,000 green eggs. This would require at least 15 females and 15 males per year. These fish and additional fish to total 60 fish, will be lethally sampled to assure protocols are met for genetic testing and disease certification. The additional fish could be fish which have already natural spawned. Means of collecting the fish would be by electrofishing or netting.

Findings: No activity was conducted this report year.

GEOCHEMISTRY

Project title: Geochemistry of Thermal Springs

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Additional investigators: Cindy Wilson, William Woessner

Objective: The overall objective in Dr. Hinman's research group is to identify controls on the chemistry of springs, runoff channels, and groundwater in thermal areas. Specifically, Dr. Hinman's group studies dissolved, particulate and mineral-precipitate composition to understand the chemical, physical and biological processes that control the chemistry of thermal spring environments.

Findings: Chemistry of sinter deposits: We investigated the atomic environment of hydrothermal silica minerals. We predict that these signatures, once interpreted in modern systems, can be used to predict silica reactivity and to determine formation environments in the past, including potential biological influences. During the summer of 2002, a preliminary study of Al in siliceous sinters from various locations around Yellowstone National Park revealed the very interesting result that only tetrahedral Al is present. We had expected to see some octahedral Al but unfortunately, undetected background signals obscured the octahedral Al signal and we cannot be certain whether it is present.

Groundwater–surface water interactions: Surface water and groundwater exchange chemical through the biologically rich hyporheic zone at Rabbit Creek, Firehole Drainage, Yellowstone National Park. Hydrothermally fed creeks are unique because mineral-rich thermal water precipitates minerals that line the outflow channels restricting surface water–ground water exchange. Our results show losing sections of the creek have chemical and biological conditions leading to mineral deposition. Seasonal changes in chemical conditions are observed.

Project title: Niche Partitioning in Late Pleistocene Mammals of North America: A Test Combining Isotopic and Morphologic Data

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Additional investigator: Dr. Edward Davis

Objective: Niche partitioning has been shown in ancient animals in environments where both C3 and C4 flora are present, but partitioning has rarely been shown in strict C3 environments even though before seven million years ago in North America and above 45T° N latitude only C3 flora were present. The objectives of this study will examine niche partitioning in large herbivores in the C3 dominated environment of Yellowstone National Park by analyzing stable isotope values in both tooth enamel and fecal material, and cranial and post-cranial morphology of skeletal material from recently deceased animals. I intend to investigate how large herbivores partitioned resources, such as forage and space by analyzing carbon and oxygen isotope values and morphology.

This study will be used as a model for comparison to fossil faunas to determine how large ungulates partition resources in a C3 dominated environment. Yellowstone National Park and the Greater Yellowstone Ecosystem provide ideal sites for this type of study. Yellowstone National Park is predominantly C3 in its flora and has the largest diversity of ungulates of any single ecosystem in North America.

In this study, I intend to answer the following questions: (1) How is niche partitioning among large herbivores accomplished in a C3 dominated environment? (2) How well are the partitioning patterns reflected in the isotope data? (3) Is there any correlation between morphology and stable isotope values? (4) Is there any correlation between terrestrial vertebrate oxygen isotope values, and those found in modern precipitation? (5) How well do the patterns in resource use observed today match the patterns for similar animals during the Pleistocene (about 15,000 years ago)?

I intend this investigation to shed light on specific ecosystem dynamics in Yellowstone National Park, and aide in our interpretations of fossil faunas. I believe this study will increase our understanding of the interactions between mammals, and the interactions between plants and mammals within particular ecosystems. Understanding the ranges of particular flora and the interactions of mammals within a particular ecosystem will add to the knowledge from previous studies in Yellowstone and will help us to better understand the paleoecology of fossil faunas and ancient ecosystems.

The herbivores to be included in this study are Bison (bison), Antilocapra (antelope), Odocoileus (deer), Alces (moose, if possible), Cervus (elk), Oreamnos (mountain goat, if possible), and Ovis (Bighorn sheep). Tooth enamel samples (from recently dead animals) and fecal material will be sampled for stable carbon and oxygen isotope ratios, while cranial and post-cranial skeletal material (from recently dead animals) will be measured for data on body size and form.

Carbon and oxygen isotope ratios from the herbivores will be obtained from the carbonate in tooth enamel as well as fecal material (carbon isotope only). The morphological data to be gathered include but are not confined to length and width measurements on long bones as well as measurements on tooth row length and the Hypsodonty Index (tooth crown height/tooth crown width). Mean differences for both the isotopic and morphologic data between genera will be statistically compared using ANOVA and/or the Kruskal–Wallis non-parametric tests. Significance will be determined at the $P<0.05$ level.

Findings: Fecal material was collected for five of the seven large ungulate genera within Yellowstone National Park. Included were Bison (bison, 30 samples), Antilocapra (antelope, 20 samples), Odocoileus (deer, 10 samples), Cervus (elk, 30 samples), and Ovis (Bighorn sheep, 20 samples), while Alces and Oreamnos could not be found. Most of these samples were fresh to insure correct identification. These samples are currently being freeze dried and prepared for isotopic analysis as of February 15, 2003.

Carbon and nitrogen isotope data should be available by late spring 2003.

Most of the samples occurred in the northern portion of the park. The bighorn sheep and deer samples were mainly taken from Mt. Washburn. Antilope samples were mainly taken from Mt. Everts and the surrounding areas. Bison samples were mainly taken from the Hayden Valley area. And elk was collected all over the park.

Enamel isotope samples were obtained from Cervus specimens collected by the Wolf Project. In total 30 samples were taken. Twelve adult female samples, eight adult male samples, five juvenile female samples, and five juvenile male samples. Morphological characteristics were also measured on the skulls from which the isotope samples were taken. The measurements included skull length, tooth row length, palate and muzzle widths, occipital width, as well as individual tooth measurements such as tooth length, width, and length of enamel.

The Cervus enamel has been isotopically analyzed, and values for all individuals suggest, as expected, feeding on a C3 dominated diet. There appears to be no difference in feeding between either the males and females, or juveniles and adults.

On a nuturalist bent, other large mammals spotted, of note, include wolf, red fox, and a grizzly mother with cub near Fishing Bridge.

The current status of the project is continuing. The fecal analysis needs to be completed and should be so by late spring 2003. I would also like to gather more fecal samples focusing on deer, moose, and mountain goat (if possible) to supplement the material and data already collected. I expect this project to be completed by December 2003.

Project title: Water Chemistry and its Relationship to Local Geology: A Yellowstone Case Study

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Objective: This study is an ongoing component of Geology 329 taught from the Indiana University Geologic Field Station, Cardwell, Montana. During the field-based class, undergraduate students involved with several environmentally oriented programs (chemistry, biology, ecology, geology, and environmental science) on campus, are involved in their first intensive field experience. The objectives of the Yellowstone study are twofold. First, the YNP field trip is a unique opportunity to look at an ecosystem that is heavily influenced by hydrothermal activity, which is in stark contrast to the riparian and montain systems found in study areas of the Tobacco Root Mountains. During the weeks preceding the Yellowstone trip, the students engage in the collection of field measurements of various aquatic systems encountered in their study areas. This data (including oxidation-reduction potential, pH, temperature, and specific conductance) is used as a comparative set against the data collected in the select thermal features of Yellowstone. The range of values encountered in the Yellowstone features gives some extreme values for real world data sets and illustrates how temperature controls many of the other chemical variables and microbial ecosystems.

Secondly, plotting the data on topographic maps gives some notion of the distribution, and the compartmentalization of the thermal features, in contrast to typical watershed studies. In addition, the real time data that the students collect and plot, is compared to the plots of the field data from the USGS Bulletin 1303 (Rowe et al. 1973) which was collected in the 1960s. The data illustrate the geologically ephemeral nature of the features when compared to time scales of other geologic processes observed and discussed during the course.

Findings: On June 28, 2002, Park Ranger Julianne Baker accompanied the group through the Upper Basin at Norris. The group took four sets of field measurements (oxidation-reduction potential, pH, temperature, and specific conductance) at 18 thermal features along the public boardwalk. Over lunch, the data were compiled and plotted on a copy of the map figure from (Rowe et al. 1973). The data was then compared to the published data from USGS Bulletin 1303 to see which features were new in the last 40 years, which had cooled or were inactive, and where the current hot spots were today. Data were compiled and sent to Norris to add to the data base.

Later in the afternoon, the group visited Octopus Spring for a look at the controlling factors in the distribution of microbial communities. Groups again took field measurements along the runoff channel to observe how temperature controls the chemistry and the distribution of the various microbial communities. Students plotted their data along their sketched map of the spring and runoff channels. Eight water samples were collected; H2S (HS-), SO42-, and Cl- were trapped with Zn-acetate, BaCl, and AgNO3, respectively, to form precipitates from the pool, and three points of increasing distance from the spring. These precipitates were filtered, weighed, and the concentrations of these constituents calculated by the students two days later, at the Field Station. Care was exercised to leave the thermal features as undisturbed as possible, and to avoid reactants making it into the environment.

Project title: Water Analysis of Hot Springs in Yellowstone National Park, Wyoming

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Additional investigators: Dr. Richard D. Foust, Jr., Molly S. Costanza-Robinson, Van S. Blackwood

Objective: Do trace chemical analysis of several springs in the Norris Geyser Basin to support microbial studies conducted by Professor Gordon Southam.

Findings: Major and minor chemical constituents in these springs agreed with previous studies in Yellowstone Park and with specific studies on these springs. Unusually high fluoride levels (70–74 ppm) were observed in several springs. Unusually high tungsten levels (0.1–0.23 ppm) were observed in several arsenic hot springs.

Project title: Geochemical and Geophysical Investigations of Mine Impacts and the Soda Butte Creek Watershed, Yellowstone National Park

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Additional investigator: Lori Eversull

Objectives: The objectives of this project are to examine the geochemical systems of the Soda Butte Creek watershed, and to investigate the impact of mining activities near the Creek's headwaters on stream and sediment chemistry. This is accomplished through: (1) building a long-term database documenting seasonal and annual variations in stream chemistry and metal concentrations in stream waters and sediments, and (2) delineation of shallow subsurface features in the Soda Butte Creek floodplain.

Findings: Sediments and water of Soda Butte Creek and selected tributaries were sampled in the first week of June 2002. Streambed sediment and water were collected at 12 locations along Soda Butte Creek from the headwaters north of Cooke City to the confluence with the Lamar River. High flow conditions blocked access to the McLauren tailings and also prevented sediment collection immediately downstream of Warm Creek. Additional samples of streambed sediments and water were collected from Warm Creek, Pebble Creek, and the hydrothermal drainage at Soda Butte Mound. Analysis for metals in all 2002 samples is pending.

At each site, stream water pH, redox potential, total dissolved solids (TDS), conductivity and temperature were also recorded. These data were consistent with data collected in previous years during high stream flow conditions. Water from all sites along Soda Butte Creek as well as the major tributaries (Republic Creek, Pebble Creek and Warm Creek) is slightly alkaline, with pH values ranging from 8.1 to 8.8. The small hydrothermal creek near Soda Butte Mound is consistently more neutral in pH, with a pH of 6.7 recorded in June 2002. TDS values for Soda Butte Creek, Pebble Creek and Republic range from 35 to 72 ppm in 2002. Warm Creek and the Soda Butte Mound hydrothermal creek are typically higher in dissolved solids (166 and 152 ppm, respectively).

Also completed in 2002 was an investigation of the mineralogy of Soda Butte Creek sediments. Initial results of this study were included in the 2001 IAR and were published in January 2002 by the Mississippi Academy of Sciences <http://www.msstate.edu/org/MAS/mas02.pdf>.

Project title: Geochemical Baselines in the Greater Yellowstone Area

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Additional investigator: Daniel Norton, Harley D. King

Objective: (1) Provide objective, unbiased geochemical baseline data for about 50 chemical elements determined in samples of rock, active stream sediment, water, plants, and animal scat collected from scattered localities throughout Yellowstone National Park and the adjacent U.S. Forest Service lands. (2) Identify the sources, such as hydrothermal features, past mining, and recreation, of anomalous concentrations of selected elements. (3) Determine the chemistry of selected elements in the food chain and how these elements may impact the health of wildlife in the park. (4) Publish raw data and interpretive reports on results.

Findings: About 600 samples of stream sediment, rock, water, and/or animal scat have been collected from widely scattered sites in and around YNP. These samples have been analyzed for as many as 50 elements. In the northeastern part of the park, weakly anomalous levels of elements related to mineralized rock or to past mining in the Cooke City area have been detected in samples from the Soda Butte Creek drainage basin. These weak anomalies extend to the confluence of Soda Butte Creek with the Lamar River, where sediments from that stream with only background levels of most elements dilute the anomalous concentrations from Soda Butte Creek to background levels. In the fossil (dead) and active hydrothermal areas of the park studied to date (mainly areas of geysers and hot springs), a common suite of elements is generally present in water and sediment downstream from each area. Concentrations of some elements that are potentially toxic to animals, such as arsenic and fluorine, are significantly elevated in downstream water and sediment. Such elements can be taken up by plants that are consumed by animals. Concentrations of other potentially toxic elements, such as lead and selenium, are very low in the park and thus are not considered to be a significant health issue. Cesium seems to be the best unique indicator of hydrothermal activity. Analyses of over 100 samples of bison and elk scat show anomalous concentrations of elements associated with hydrothermal features for those animals foraging near such features, indicating that animals foraging in such areas are ingesting significant amounts of elements such as arsenic and fluorine. The toxic effects of fluorine on elk have been documented by others. The effects on animals of ingesting large quantities of many of the elements determined for this study are not known. Data are lacking on the amounts of elements, such as arsenic and molybdenum, that are being retained nd accumulated in animal tissue.

Project title: Arsenic Geochemistry in Yellowstone National Park: Occurrence, Speciation, and Transformations

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Additional investigators: Blaine McCleskey, Sarah Lovetere, Joanne Holloway, James Ball

Objective: The prime objective is to determine the processes that control the concentrations and redox speciation of arsenic in geothermal springs, geysers, and their overflows. As(III) and As(V) will be determined routinely. As methods are developed, determinations will be made for methylated arsenic, thioarsenite, and arsine gas. Processes that mobilize arsenic, precipitate arsenic, and oxidize arsenic will be examined. Arsenic oxidation rates and mechanisms will be determined and compared to known lab rates.

Findings: During 2002, 36 samples were collected and analyzed for all major ions and most trace elements including As(III/V), Fe(II/III), and S redox species. Monitoring of the thermal activity at the Ragged Hills area continued and some new areas were also sampled such as Black Pit, Bathtub Spring, Calcite Springs, and new areas in the Ragged Hills. Determinations for volatile metalloids were attempted for the first time and some successful results showed the occurrence of volatile (probably methylated) arsenic compounds in parts of Norris Geyser Basin and nearby at Hazle Lake. This work was initiated by Britta Planer-Friedrich as part of her Ph.D. research at Freiberg Technical University, Germany. An arsenic oxidation study in the overflow from Ojo Caliente was also executed. Four reports were published during 2002 on arsenic geochemistry and two of these directly pertain to work done at Yellowstone National Park.

Project title: Sulfur Speciation and Redox Processes in Mineral Springs and Their Drainages

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Objective: The prime objective is to determine the fate of geothermal H^2S from hot springs and geysers. The hypothesis is that H^2S can undergo both oxidation in solution and volatilization. The amount oxidized and remaining in solution will be determined by analyzing waters for thiosulfate, polythionates, sulfite, sulfate, and H^2S. Sulfoxyanions will be determined using ion chromatography in a mobile chemical laboratory that can be located at or near the site. The origin of thiosulfate and its importance to mineral deposit formation will be studied and the rate of thiosulfate formation from H^2S will be measured in hot spring overflows where possible.

Findings: In 2002, we sampled 36 hot springs, lakes, and streams and analyzed them for all major ions, most trace elements including sulfur redox species, Fe(II/III), and As(III/V). We have found that arsenic oxidation rates are controlled by the presence or absence of reduced sulfur species, especially H^2S and thiosulfate. Both of these sulfur species keep arsenic in the reduced As(III) state. This phenomenon has been known for a long time in the laboratory but it has not been previously noted in thermal waters.

Project title: Student Project to Measure Geochemistry of Thermal Springs

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Objective: To teach students about some of the physical and chemical properties of thermal hot springs.

Findings: Our group made the following measurements on July 27, 2002. Units reported are: Temperature in degrees Centigrade, Specific Conductivity (SC) in milliSiemens/cm.

Norris Geyser Basin
- Minute Geyser: T= 45; pH=6.8; SC= 2.5
- Branch Geyser: T=81; pH=4.6; SC=3.2
- Fearlesss Geyser: T=89; pH=5.9; SC=3.0
- Palpitator Spring: T=83; pH=6.5; SC=2.7
- Vixen Geyser: T=85; pH=3.3; SC not measured
- Pearl Geyser: T=80; pH=7; SC=3.9
- Son of Green Dragon: T=89; PH=2.9; SC=3.5
- Grandson of Green Dragon: T=91; pH=3.7; SC=3.7
- Mystic Geyser: T=92; pH=4.2; SC=1.9
- Crater Spring: T=92; pH=5.8; SC=2.4
- Whirligig Geyser: T=67; pH=3.7; SC=2.8
- Whale Mouth Geyser: T=51; pH=4; SC=1.7

Lower Geyser Basin, White Creek
- geyser upstream of Octopus Spg.: T=89; PH=8.2; SC=1.6

Mammoth HS area, Narrow Gauge Spg.: T=68; pH=6.7; SC not measured.

GEOLOGY

PROJECT TITLE: THE SEARCH FOR MICROBIAL BIOMARKERS IN TERRESTRIAL DEPOSITS

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Objective: The primary purpose of this investigation is to evaluate the fossilization process and the potential for a long term record of the microbial life that exists associated with hot springs and their deposits. Basically, we are looking for biomarkers, indicators that microbes once existed as part of the hot spring environment. This will allow us to determine the likelihood of finding fossilized microbes in extraterrestrial bodies (e.g., Mars) and what is the most likely preserved material. For example, will we have a better chance of finding body fossils or geochemical indicators of former organisms.

In order to carry out this investigation, we have and will continue to analyze the waters from which the mineral precipitates originate as well as the solid precipitates. It is our intent to search for mineralogical (crystal habit, size, etc.) and geochemical (major, minor, and trace elements as well as isotopic) differences between biotically induced and abiotic precipitates as well as microbial remains (bacterial body fossils, biofilms, etc.). In the past, we have investigated carbonate and siliceous sinter deposits, we intend to modify this work to include Mn- and Fe-rich hot spring mineral deposits. Some hot springs at Yellowstone provide an ideal natural laboratory in which to conduct this avenue of research. Among the sites that we would like to visit to determine their feasibility for detailed study include: Terrace Spring (near Madison), Pine Cone Geyser (Lower Geyser Basin), Locomotive Geyser and Black Sulphur Spring (Shoshone Geyser Basin), Fissure Group (Heart Lake Geyser Basin), White Creek area, Hot Lake area, and Chocolate Pots. All of these sites have been reported to have Mn- and Fe-rich mineral deposits. Recognition of biotically induced mineral precipitates will be based on: macroscopic form of the precipitate, presence of microbial fossils, oxidation state of the metals, saturation of the waters with respect to the mineral precipitates, and isotopic fractionation of the metals in the precipitates. This avenue of research has not been previously conducted in Yellowstone. Laboratory and field investigations at universities and other field sites indicate that this area of research holds great promise of providing insights into biotic vs abiotic mineral deposition. An area in which this research is relevant pertains to the search for life on Mars, remote sensing of the Martian surface suggests that large areas may be covered by Mn- and Fe-rich spring-related deposits, are they biotic or abiotic and how can we tell. Additionally, the origin of Mn- and Fe-rich deep sea nodules has long been debated, this research can shed light on that debate. This is a new and exciting area of investigation and Yellowstone is the ideal site to perform the field work associated with this research.

Findings: Our work has demonstrated that the microbes readily decay in the rock. We have sampled from cores taken through the siliceous sinter and have compared these analyses with those of modern material forming on the surface of the hot springs. Within a few meters depth, samples in which macroscopic forms clearly demonstrate that microbes were present in abundance (e.g., stromatolites), have no remnants of the biochemical materials that are present in the surface materials. That is, decay of the organics occurs very shortly after the rock is formed. This unexpected result is not surprising considering the porous nature of the sinter and the hot, acidic, oxygen-rich waters that are constantly coursing through these deposits. Additionally, siliceous preservation of the microbes as body fossils becomes obscured as additional silica is deposited around these tiny fossils. These results indicate that hot spring deposits on Mars may not be the ideal site to look for evidence of preexisting life.

Project title: Study and Monitoring of Selected Geyser Activity

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Additional investigator: James B. Grigg

Objective: This study aims to record the long-term activity of selected geysers and hot springs using electronic data loggers to record runoff water temperatures. For geysers, analysis of the temperature record allows determination of the eruption start time and, for some geysers, the eruption duration. By recording the activity of numerous geysers and hot springs spatially distributed around the Yellowstone thermal systems, both local and system-wide occurrences can be tracked.

Some of the geysers in this study have been monitored for several years, the earliest records being from 1995.

In 2001, the author also has been operating a number of data loggers belonging to the National Park Service. The author's loggers along with the NPS-owned loggers permit wider coverage of Yellowstone thermal activity.

Findings: As of the end of 2002 data from more than 35 thermal features has been collected and analyzed. Over the winters of 2001–02 and 2002–03 about 30 data loggers have been deployed, allowing nearly continuous records of activity.

Analysis of the thermal records through the end of 2002 is nearly complete as of February 2003. Some long-term trends are evident in the eruptive activity of several geysers; for example Old Faithful, Daisy, and Castle have all exhibited a gradual increase in interval between eruptions.

The Alaska earthquake of 3 November 2002 was followed by large changes in the activity of Daisy Geyser (which decreased its intervals by about an hour) and Castle Geyser, which increased its intervals by about an hour. Changes were observed in the activity of Plume and Depression geysers also.

All of the temperature records and EXCEL spreadsheets with graphs of activity and statistical analysis of most of the monitored geysers are on file at the Yellowstone Center for Resources and with the author.

About 30 data loggers are deployed for the winter, including both the author's loggers and loggers owned by the NPS, and current plans are to continue monitoring of approximately 40 thermal features during the summer of 2003.

Project title: Preservation of Organisms in Sinter, and Study of Sinter Textures

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Additional investigators: Lyall Anderson, Ruth Kelman, Steve Fayers

Objective: We are part of a research team at Aberdeen University, Scotland, working on the fossil biota and palaeoenvironments of an Early Devonian hot spring system at Rhynie, Scotland (see http://www.abdn.ac.uk/rhynie). Our studies in Yellowstone are related to the identification of modern analogues for the ancient hot spring deposits. Thus we are looking at preservation of biota in sinter, sinter textures, and hot spring vents.

Findings: We have conducted studies at various hot springs in the park, and have found sinters with textures closely comparable to those seen in the Early Devonian Rhynie chert of Scotland. Textures have been recorded that are typical of both terrestrial and lacustrine deposition. Preservation of plants and arthropods in Yellowstone sinters shows many similarities with the Devonian fossils, but there are obvious differences, notably resulting from the role of diatoms in the modern environment.

We can conclude that the Rhynie cherts probably formed at temperatures below 35°C in outwash streams and pools at the distal end of a sinter apron from a hot spring.

Project title: The Emergence of Scale-Invariant Architecture in Rimmed-Pool Carbonate Terraces: Abiotic Controls in Surface Hot Springs and Subsurface Cold Springs

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Additional investigator: George Bonheyo

Objective: The goal of this study is to determine how the phylogenetic and functional diversity of specific microorganisms influences the development of terraced crystalline mineral deposits universally observed in high-temperature and low-temperature carbonate spring systems. Results will provide a fundamental knowledge of microbe-water-mineral interactions during carbonate precipitation that are needed to more accurately reconstruct the history of microbial life on earth and other planets. This project advances the field of biocomplexity by combining geological studies, microbial rDNA and gene analyses and quantitative modeling to provide a detailed geobiological account of carbonate terrace formation.

The project is being completed by an interdisciplinary research team with specific expertise in geology, microbiology, and physics. Project milestones will include: (1) performing in situ crystallization experiments to determine the form and chemistry of travertine deposited when the microbes have been UV-irradiated, a sterilization technique that will leave the other fundamental physical and chemical conditions of the spring drainage outflow relatively unchanged; (2) documenting associations between calcite crystal growth form, distribution and chemistry with microbial form, diversity and metabolic activity; and (3) quantitative modeling of carbonate terrace formation using stochastic differential equations to describe the combined effects of geological and biological processes.

Mammoth Hot Springs is the most uniquely well-suited natural laboratory in the world for conducting the proposed research. Although CO^2 degassing and decreasing temperatures strongly influence the spring water chemistry, significant biological controls on travertine crystal form and isotope chemistry have recently been quantitatively documented. Mammoth Hot Springs uniquely offers: (1) precipitation rates as high as 5 mm/day that allow short-duration in situ crystallization experiments in a regime of coupled biological and physical influences; (2) the full spectrum of high- to low-temperature carbonate precipitates at one site; (3) long-term familiarity of the study site by the PIs who have all required research permits in hand; and (4) the only easily accessible hot spring complex in the world protected in its natural state.

The main question addressed is whether the presence of terraced carbonate mineral architecture is prima facie evidence for the presence of microbial activity. Results from this study will permit the identification of microbiologically influenced crystallization in other modern and ancient high-temperature and low-temperature terraced carbonate spring deposits. The techniques employed in the quantitative modeling provide a first principles understanding of significant geological features from a physical and biological perspective. Of equal importance, the results from this study will establish a systematic and quantitative toolkit to identify microbial influence during carbonate deposition that can be used in a wide variety of other important terrestrial, marine, and burial environments on earth and other planets.

Findings: Five depositional facies (vent, apron channel, pond, proximal slope, and distal slope) have been documented based on water chemistry and travertine crystal form and chemistry. Robust coupled physical and biological signatures in crystal shape and chemistry make Spring AT-1 the best-suited natural laboratory in the world to study biological controls on carbonate mineralization. Significant diurnal variations in microbial communities and water chemistry occur at Spring AT-1, but little to no seasonal variations. The position of the Spring AT-1 vent has remained stationary for the last five years, while the position of the outflow channel and the flow rates have fluctuated. After each fluctuation, the depositional facies are systematically re-established along the spring outflow.

The aqueous chemistry of the hot spring drainage system is dominated by CO^2 degassing and dropping temperature as proven by Rayleigh-type fractionation calculations of spring water d13C versus dissolved inorganic carbon (DIC). While these physical factors help drive the rapid precipitation of carbonate crystals to deposit travertine at rates as high as 5 mm/day, they are not the exclusive controls on precipitation. Significant biological controls on travertine crystal form and isotope chemistry have been identified with petrography (e.g., crystals entombing and preserving the shape of filamentous Aquificales bacteria) and by quantitative subtraction of degassing and temperature effects on d13C and d18O isotopic fractionation. These robust disequilibrium signatures may be biologically mediated and systematically increase in magnitude from the high (73°C) to the low (<25°C) temperature portions of the Spring AT-1 outflow. Preliminary 16S rRNA screening at Spring AT-1 revealed 350 bacterial sequences (3% difference) representing 22 bacterial divisions, which exhibit a remarkable 85% partitioning between facies. Thermodynamic saturation state of the spring water stops increasing at the pond facies. This coincides with and may reflect a metabolic transition from predominantly autotrophic to predominantly heterotropic bacterial communities.

In order to simultaneously assess the composition of all "active" members of the microbial assemblage along the Angel Terrace system, and to identify those associated with defined ecotypes (aqueous or crystalline), we have recently designed and assembled a pilot rDNA microarray. The array is comprised of 95 partial (200 bp) rDNA sequences representing the extent of diversity found in the rDNA surveys. If proven to be effective in providing specific rRNA hybridizations, this technology will be a significant asset to the proposed study, since it will facilitate rapid determination of the biologically active portion of the microbial community associated with different geological ecotypes, in a high-throughput fashion. The pool rim environment, where travertine accretion rates reach 5 mm/day and the carbonate terrace morphology is generated, will be the focus of this study.

GEOMORPHOLOGY

Project title: Holocene and Modern Geomorphic Response to Fires, Floods, and Climate Change in Yellowstone National Park; Natural and Anthropogenic Influences on Stream Systems

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Additional investigator: Dr. Paula M. Watt

Objective: To provide a long-term perspective on the geomorphic impacts of the 1988 Yellowstone fires, we are investigating Holocene sedimentation in northeast Yellowstone, using post-1988 fire-related events as a guide for interpreting alluvial fan stratigraphy. Comparison of the timing of fire-related events with climate proxy records elucidates the relative controls of climate, fire, and intrinsic geomorphic thresholds on alluvial systems. We are documenting extreme floods of the last ~300 years and their effects on valley floor landscapes of northeast Yellowstone. Recent changes in stream channels seen through analysis of air photos, historical photos, floodplain stratigraphy, and resurveying are evaluated in the context of flood history, riparian vegetation, ungulate browsing, and intrinsic characteristics of basins and channels. A related study uses the record of beaver activity and stream dynamics contained within radiocarbon-datable beaver pond sediments to understand how Holocene environmental changes have affected beavers and their stream habitats in the area of Yellowstone's northern range. We are also studying a 1950 dam failure at Cooke City, Montana, that deposited acidic, metals-rich mine tailings along the Soda Butte Creek floodplain.

Findings: Our study of the geomorphic response to fires is largely complete. This work shows that large crown fires as in 1988 have been an important catalyst for landscape change in Yellowstone, for at least the last 5,000 years. The occurrence of such fires is strongly controlled by climate on ~1,000-year time scales. In cooler climates such as within the Little Ice Age ~1200–1900 AD, large severe fires and their attendant debris flows are rare, whereas during warmer periods (e.g., 900–1200 AD), episodic severe droughts result in widespread debris-flow activity. Mainstem streams also undergo fluctuations in activity over these timescales that cause major changes in floodplain character. Our work has also identified major floods in the Lamar River system in 1918, the early 1870s, and possibly near 1800. These floods had much greater peak discharge than the 1996 and 1997 floods, which are the largest in current stream gauge records, and are often called "100-year floods." The extensive dry gravelly deposits of the 1918 and early 1870s flood have had lasting impacts on stream channels and valley floor ecosystems. The 1950 tailings dam break produced extreme discharges but had short duration, thus causing little erosion. However, tailings deposits along Soda Butte Creek have significant copper and lead content, impact floodplain vegetation, and continue to be eroded into the channel, adding to mining-related metal pollution. Copies of articles related to these studies have been supplied to Yellowstone National

Park, and are also available from the principal investigator (gmeyer@unm.edu). Preliminary study of beaver pond deposits suggests that there is a rich history of beaver-stream interactions extending back at least 3,000 years in northern Yellowstone.

Project title: Quaternary Geology and Geo-ecology of the Greater Yellowstone Area

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Objective: To document and determine the Quaternary geology and history of Yellowstone, the relation between the Quaternary geology and ecology of Yellowstone, and neotectonic features of Yellowstone, including faulting and caldera unrest based on Yellowstone Lake and River level changes.

Findings: A report was written and open-filed on Post-Glacial Inflation-Deflation Cycles, Tilting, and Faulting in the Yellowstone Caldera Based on Yellowstone Lake Shorelines. Uplift and subsidence of the central part of the Yellowstone caldera results in water-level changes in the outlet reach of the Yellowstone River and Yellowstone Lake. A reconstruction of the changes in the level of Yellowstone Lake in post-glacial time time shows five or more oscillations of lake level about an overall lowering of lake level. After 8,000 years ago the lake has been below or near the present level, including an interval 3,000–4,000 years ago when it was about 7 m below present.

For cosmogenic dating of Pleistocene glaciation of the greater Yellowstone glacial system, samples were collected from the tops of glacial boulders on moraines. The samples collected last summer are in the process of analysis.

In regard to interpretation of the geology of Yellowstone, I discussed and commented on materials for the new museum at Canyon Village. I co-led a field trip for congresssional staffers through Yellowstone. I also prepared a field guide to the Quaternary geology and ecology of the greater Yellowstone area for two field trips and a guidebook published in 2003. An overview of Rocky Mountain glaciation was written for publication in 2003 and the chronology of Yellowstone compared with other sites in the Rocky Mountians.

For archeological studies, I worked with Ann Johnson and archeologists at the Osprey site east of Grant Village on the relation to the S4 shoreline, sediment burial of paleoindian materials, and collected radiocarbon samples.

GEOPHYSICS

Project title: Operation of the Yellowstone Seismic and GPS Network (Yellowstone Volcano Observatory) and NSF Project (Geodynamics of the Yellowstone Hotspot)

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Objective: The Yellowstone seismic and GPS network is the main monitoring system of the Yellowstone Volcano Observatory (YVO) and serves as part of the NSF project, Geodynamics of the Yellowstone Hotspot. The network is an integrated, real-time system for recording earthquakes and ground motion of Yellowstone National Park and surrounding area focusing on the Yellowstone volcanic field and associated fault zones. Specific objectives include: (1) operation of the 23-station seismic and 5-station GPS (Global Positioning System), (2) routine station installation, maintenance and upgrading, (3) data recording, processing, analyses, and archiving, and (4) web accessible distribution of the data from these systems. Information from this network are provided to the National Park Service and USGS management, NPS public safety and interpretation groups, as well providing on-line data for scientific research for all users.

In this report period we expanded our efforts to expand the USGS Yellowstone Volcano Observatory (YVO) monitoring utilizing the University of Utah as the base of operations. The USGS Volcano Hazards Program jointly funds this cooperative project with partial support form the National Park Service for fieldwork. The primary products of the project are earthquake catalogs, ground deformation data, the services of a regional earthquake and precise GPS recording and information center, including timely release of unusual volcanic and earthquake activity reports to the USGS and the NPS. In addition, the National Science Foundation and the University of Utah have provided funds for three of the GPS stations and for basic research on the Yellowstone Hotspot project.

Findings: Yellowstone seismicity: Epicenters of 2,278 earthquakes (M<= 3.2) were located in the Yellowstone region during the report period. The largest earthquake during the report period was a shock of magnitude 3.2 that occurred on November 20, 2002 (02:14 UTC), located 23 miles south southeast of West Thumb, Wyoming. Note that many of the earthquakes were part of a triggered sequence triggered by the passage of strong waves from the November 3, 2002, M7.9, Denali, Alaska, earthquake over 3,000 km away, discussed below.

Earthquake and hydrothermal response of the Yellowstone volcanic field to the M 7.9 Denali earthquake: The November 3, 2002, Alaska earthquake had a profound effect on the Yellowstone volcanic field by triggering a dramatic increase seismicity and pronounced changes in hydrothermal features.

Following passage of the Denali main-shock surface waves, tens to hundreds of earthquakes, $-1 < M < 2.7$, were recorded throughout Yellowstone National Park. In the first week following the main shock, more than 400 earthquakes were recorded. The earthquakes were extant over the entire Yellowstone volcanic field with notable activity in the southeast and northwest caldera. In addition, much of the triggered seismicity was associated with unusual variations in geothermal activity. The Yellowstone Volcano Observatory responded by timely reporting of the earthquakes and notation of significant changes in seismic activity to Yellowstone NPS and USGS officials.

Seismic imaging of the crustal structure of the Yellowstone volcanic field: The 3-D P-wave velocity and P- to S-wave velocity-ratio structure of the Yellowstone volcanic field was determined from local earthquake tomography using new data from the permanent network. The results confirm the existence of a low P-wave velocity body at depths greater than 8 km possibly representing hot, crystallizing magma beneath the Yellowstone caldera. In addition, P-wave velocities and P- to S-wave velocity-ratios, show an anomalously large decrease in the northwestern part of the Yellowstone volcanic field at shallow depths of < 2.0 km. Theoretical calculations of changes in P- to S-wave velocity-ratios indicate that these anomalies can be interpreted as porous, gas-filled rock.

GPS monitoring of Yellowstone ground motion: During the report period principal effort was focused on: (1) operation of the 5-station permanent GPS network, and (2) completion of processing and interpretation of observations made in 2000 for the ~140 GPS points in and around Yellowstone. Station positions from each year were combined to obtain the station velocities for the network. Results show that the Yellowstone Plateau exhibits anomalously high rates of park-wide crustal deformation of ~4 mm/yr SW extension with a concentrated zone of uplift from 1995–2000 centered at Norris Geyser Basin at ~2 cm/yr. However the central and eastern caldera appeared to subsiding.

Geodynamics of the Yellowstone hotspot—The study includes seismic and GPS investigations of the possible plume-plate interaction that is hypothesized for the Yellowstone Volcanic Field. Regional deformation by GPS reveals dominant NE-SW extension of the entire system. Seismic tomography reveals low-velocity crustal bodies beneath Yellowstone and an upper mantle P- and S-wave low-velocity anomaly flanked by high velocities. The mantle low-velocity body extends in depth from 90 km to 200 km and is indicative of decompression melting. These observations suggest a non-plume interpretation with melt ascending beneath the hotspot.

Publication and presentation of results: In total, University of Utah Yellowstone researchers have published and presented papers on their Yellowstone research projects including: (1) one paper in a national journal, (2) submitted three papers to national journals, and (3) made ten presentations at national and international meetings. In addition, Dr. Smith gave a ranger training lecture spring 2002 in Yellowstone.

GEOSEDIMENTOLOGY

Project title: The Structure, Facies, and Deposition of Siliceous Sinter Around Thermal Springs: Implications for the Recognition and Study of Early Life on Earth and Mars

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Objective: (1) To study the texture, morphology, and structuring of siliceous sinter deposited around hot springs and geysers in YNP and to determine the physical, chemical, and biological controls on its deposition; (2) to characterize the role of thermophilic (high temperature) organisms in the deposition and structuring of siliceous sinter; (3) to compare the structuring of siliceous sinter deposited around Yellowstone hot springs and geysers with that of siliceous rocks 3.5–3.0 billion years old to determine if any of these ancient rocks represent hot spring deposits and if there is any evidence of biological influences on their deposition; and (4) to evaluate whether there are features of siliceous sinter that are diagnostic of biological influences that could aid in the possible identification of organisms in hot spring deposits on other planets, especially Mars.

Findings: Investigations to date have emphasized the hydrodynamic controls on the structuring and morphology of siliceous sinter around alkaline hot springs and geysers in YNP. This research has been divided into two parts: (1) an investigation of low-temperature (less than 73°C) sinter deposits, where microbial mats play a major role in the structuring and deposition of sinter at all observational levels, and (2) an investigation of high-temperature (greater than 73°C) sinter where thermophilic microbes are obvious as mats but where thin biofilms probably coat most surfaces and may play a role in mediating silica precipitation rates and influencing the structure and texture of siliceous sinter. Our results to date indicate that within the high-temperature zone, microbes may influence some aspects of sinter microstructure but that hydrodynamics, water cooling, and evaporation control where silica is deposited and the larger-scale structuring and morphology and most of the microstructuring of the deposits. During the calendar year 2002, work on this project included fieldwork to monitor silica deposition rates in May and writing up the scientific results for publication. One major paper on the microstructure of high-temperature sinter was submitted for publication in a special volume of the *Canadian Journal of Earth Sciences* on siliceous deposits around hot springs. If additional fieldwork is conducted in 2003 it will involve monitoring of silica deposition rate experiments already in place.

GEOSTRUCTURE

Project title: Crustal Structure and Composition of Yellowstone National Park: Relation of Crustal Structures to Geology, Hydrothermal Alteration, and Seismic Activity

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Objective: A high-resolution aeromagnetic survey flown over Yellowstone National Park shows a broad spectrum of contrasting magnetic patterns reflecting variations in rock composition, types and degree of alteration, and crustal structures. Compared with previously obtained low-resolution aeromagnetic data, which showed broad regional geologic trends, the new aeromagnetic data collected at low altitudes with closely spaced flight lines and integrated with geologic mapping, rock property measurements, and remote sensing data show this high-resolution data to be extremely useful in revealing small-scale geologic features. This method has identified fractures and areas of alteration that previously have not been mapped, identified the extent of individual geologic units and structures, and estimated the magnitude of hydrothermal alteration. Magnetic gradient trends follow the mapped north-south Basin and Range structural trends. These trends are at small scales such as in the hydrothermal basins and at larger scales such as with fault systems suggesting that the regional stress field localizes much of the present day hydrothermal activity.

Objectives in this final phase will include a focus on collecting samples for rock magnetic and other physical characteristics to refine interpretation of aeromagnetic data; examination of the interrelationship of hydrothermally altered rock units, slumping soils on steep terrains, and timing of deformation; and investigation into the interrelationship of structural trends, fossil and active hydrothermal alteration, and regional seismicity. Our focus in 2003 will be the Quaternary rhyolitic lava flows and the Quaternary ignimbrites (Lava Creek, Bluff Point, and Huckleberry Ridge Tuffs) in bulk susceptibility and magnetic fabric studies.

Findings: A recent finding from the integrated study of the aeromagnetic characteristics of hydrothermal areas in tandem with our hydrothermal explosion and Yellowstone Lake studies has identified a NE-trending structure subparallel with the NE-trending fissures on Elephant Back. This structure has not previously been described in the literature and may be active and reflect the inflation and deflation of the Yellowstone caldera. Several young hydrothermal explosion craters and young hydrothermal features occur along this structure. We plan to continue studying this feature. We also plan to continue analysis of the high-resolution aeromagnetic survey over most of YNP and compare with magnetic susceptibility and remanence measurements, focusing on the Quaternary rhyolite lavas and ignimbrites. Samples will be collected and analyzed for magnetic remanence and susceptibilities of fresh and altered volcanic and sedimentary rocks. Manuscripts describing the aeromagnetic data in terms of its usefulness in mapping volcanic flows, faults, and zones of alteration are planned. We plan to compare magnetic susceptibility, zones of alteration, oxygen isotopes, and total magnetic intensity of specific volcanic units. Magnetic fabric analyses and interpretation of possible flow directions in ignimbrites and lava flows in the Yellowstone Plateau volcanic field, based on anisotropy of magnetic susceptibility, will continue and be complimented with granulometric and component analyses.

Visual inspection of the aeromagnetic map with superposed geologic features (Finn and Morgan 2002, 2003) suggests that there may be distinctive magnetic anomaly minima associated with mapped zones of hydrothermal alteration of the source rocks. To investigate this, we want to accomplish three objectives: (1) quantify and verify the relationship between the lows and alteration and use the aeromagnetic data to map the extent of alteration zones beneath covered areas; (2) analyze the aeromagnetic map for trends, which might delineate the structural fabric of older geologic structures which controlled the loci of volcanism within the Yellowstone system; and (3) map textural measures of the aeromagnetic anomaly field which might be related to rock lithologies and thus be of use in elucidating the geologic structure. To do this, we will apply new analysis tools in conjunction with Mark Gettings (USGS, Tucson) to the data and field check the data. A paper describing the method and the case study will be published.

Geothermal/Volcanology

Project title: Volcano Emissions

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Additional investigators: Mr. Michael Doukas, Dr. Terrence Gerlach

Objective: Research on various gas emissions from fumaroles, soils, and other sources within Yellowstone National Park for the purpose of defining a background level of gas emissions to which future measurements of anomalous degassing during volcanic or tectonic unrest could be compared.

Findings: No activity was conducted this report year. The nature of this project does not require work in the park every year.

Chloride Flux Monitoring

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Additional investigators: Dr. Shaul Hurwitz, Smokey Sturtevant

Objective: To determine the annual chloride flux out of Yellowstone National Park as a surrogate for heat flux out of the park.

Findings: The total chloride flux varies ~5% from year-to-year, but has been declining for the past 19 years.

Project title: Microbial Life in Thermal Environments

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Objective: This project is a continuation of ongoing work to study the microbial populations of thermal environments. One goal is identifying and developing useful biomolecules. Of interest to microbial ecology, this work has allowed estimations of microbial diversity and abundance.

Findings: Limited sampling was performed in 2002 in the Lower Geyser Basin and White Creek areas. Analysis of these samples is ongoing. The results support previous estimations of microbial abundance and diversity.

Project title: Physical Volcanology of the Huckleberry Ridge Tuff

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Objective: The objective of the research is to collect detailed quantitative information on the internal physical and chemical stratigraphy of the Huckleberry Ridge Tuff, from representative sections within and beyond Yellowstone National Park. This information will be used to enhance understanding of the vent locations and their evolution, the timing and development of caldera collapse, the transport and emplacement of the ash flows, and the overall time-scales of the parental eruption.

Findings: My work in Yellowstone National Park is part of a much wider-scale study on the Huckleberry Ridge Tuff (HRT), and much of the work in the park is driven by understanding gained from sections outside the park. I report my findings below, numbered according to the areas listed above that were visited.

On the ridge north of Claggett Butte, I spent two days measuring and observing contact relationships between HRT Members A and B, and B and C. In the former case, I documented the sharp upwards reduction in welding intensity at the top of member A, but also found ~70 cm of vitric ash (inferred co-ignimbrite fall-out bed) between the non-welded top to Member A and the non-welded base to Member B, indicating that a time break occurred at this site between these two members. Similarly, a non-welded, but vapour-phase altered top to Member B occurred below the thin, but intensely welded Member C, consistent with a significant time break there also.

On Mount Everts, I completed logging of basal fall-out deposit sections, to document any lateral changes in beds that might shed light on early evolution of the eruption. This work indicated that even the basal fall-out bed was episodically deposited, with episodes of wind-reworking affecting the ash at three levels. Rapid lateral changes in some of the upper beds also support the notion, arrived at last year, that early pyroclastic flows of Member A were traveling down a paleovalley in the Golden Gate–

Mammoth area before filling that valley and overspilling into the area represented by the Mount Everts exposures.

At Crown Butte, I recorded Members A and B exposed on its south and west sides. In conjunction with other planned work in this area, both within and outside the park, my aim is to establish the timings and ways in which the members were built up, and what breaks there might have been between them. Here, the two members are separated by thin surge deposits, and have a break in welding intensity, both indicators of a significant time break. Further work is required here to look at how the contact changes as both Members A and B thin to the north against the old valley wall. A <1-m-thick zone rich in rock fragments (derived from the Eocene Absaroka Supergroup) occurs in upper Member A, but is absent to the north and south. I infer it to represent tuff that has slumped off valley walls, scouring regolith fragments, following the main emplacement of Member A.

On Highway 191, I worked on a section that exposed the base of HRT Member A, recording details of the basal ignimbrite. Unfortunately there are no traces of fall-out deposits here (cf. Mount Everts, where they are >2-m thick, and Madison River valley, where they are >1.7-m thick), and further work is needed to decide whether the fall deposits were once present but were scoured away by the pyroclastic flows of Member A, or if ignimbrite deposition of Member A occurred here at the same time as fall-out deposition was occurring to the east and west. Further work is also required in this area to find and document the contact between Members A and B in the light of evidence elsewhere for the time-break between the two members.

As with last year's work, I would like to thank the NPS for the opportunity to undertake work in the park. Progress on an overall understanding of the HRT eruption is coming, but slowly, and integration of observations from areas within the park with those from outside is important. No material has been prepared for publication from the 2002 efforts, but a list of sites visited and samples collected has been lodged with the Research Office at the Yellowstone Center for Resources.

Project title: Absolute Gravity and Crustal Deformation in the Yellowstone Caldera

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Objective: The objective of our project is to determine the temporal changes in gravity and crustal deformation in the Yellowstone caldera and its geyser basins. These observations are crucial for assessing sub-surface mass/density changes. Mass density changes reflect magmatic and/or hydrothermal activity and are an indicator of likelihood for eruption. In order to determine the temporal changes in gravity and crustal deformation requires us to collect repeat absolute gravity, continuous gravity, and Global Positioning (GPS) measurements in Yellowstone National Park.

Findings: In 2002, we collected relative gravity data at a one minute interval with a Scintrex CG-3M continuously for 10 days in the Old Faithful Village. This data is still being reduced and interpreted. The preliminary processed data shows large microgravity fluctuations similar in amplitude to the absolute gravity data we collected in 2000 and 2001, which argues for a persistence of this signal indicative of mass flux and/or crustal deformation in the vicinity of the southern end of the Upper Geyser Basin.

We also collected global positioning system (GPS) data contemporaneously at several locations in the southern end of the Upper Geyser Basin in 2002. This data shows significant oscillatory vertical motions (several centemeters) over very short periods (several hours to tens of hours), similar to what we observed in 2001. This local ground motion is in addition to the more broadly distributed background ground deformation of several centemeters a year that has been and continues to be well monitored. We interpret the local ground deformation to be indicative of deep pressure fluctuations below the Upper Geyser Basin, most likely attributable to fluid flow. We recently submitted a manuscript for publication which is now in review, "Newly detected pressure fluctuations in the hydrothermal-magmatic system below Yellowstone's Upper Geyser Basin: evidence for active deep fluid flow" presenting these results.

We are also exploring the relationship of the pressure fluctuations with the behavior of various geysers in the Upper Geyser Basin with Ralph Taylor. He has a NPS research permit for collecting electronically logged geyser eruption data. We have applied for a research grant from the National Science Foundation to continue and extend our preliminary work in Yellowstone's geyser basins, and collect more absolute and relative gravity data over actively deforming areas in the Yellowstone caldera.

Project title: Monitoring Caldera Unrest at the Yellowstone Caldera: A Global Positioning System (GPS) Crustal Deformation Study and Hot Springs Temperature Study by the Eastern Illinois University Geology Field Camp

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Objective: The purpose of our study is to monitor caldera unrest at the Yellowstone caldera by annually collecting GPS data and hot springs temperatures from a network of data collection points. Although the data collected in this study can contribute to more detailed monitoring efforts of the caldera, the primary goal of this project is to provide an on-going, hands-on field experience for undergraduate geology majors at the Eastern Illinois University Geology Field Camp.

Findings: During our fourth annual GPS survey on June 26–27, 2002, we deployed three Trimble 4000Ssi receivers at pre-determined GPS control stations in the park. These stations are located along a NW-SE traverse across the western part of the Yellowstone caldera. Each year, data is collected continuously for 48 hours from eight control stations. The GPS team sets up each station and trains students in overall instrument monitoring before leaving them with the receivers for four-hour intervals. The 2002 survey results indicate a change from uplift in 2001 to subsidence in 2002. Subsidence across the network ranges between 2.4 and 5.7 cm with a general decrease from north to south. There is no apparent relationship between the pattern of subsidence in the 2002 data and the caldera structure. Over the past three years, our deformation results show that the western region of the Yellowstone caldera has subsided, uplifted, and then subsided. Horizontal displacements ranged from a few mm to 2 cm. Overall displacement direction is southerly and contrasts with the general northerly direction of the previous year. At the northern end of the network, horizontal movement is more westerly. Relatively large horizontal displacements occurred at stations with relatively small subsidence values. There is no clear spatial relationship between displacement direction and proximity to the caldera axis. This deformation pattern is consistent with southwesterly displacement as defined by the regional NE-SW deformation model across the Yellowstone Plateau. A more detailed report of this study, including data tables and a map is available at: <http://spruce.gis.wilkes.edu/yellowstone/>.

A second component of our study is monitoring hot springs temperatures at selected thermal areas within the Yellowstone caldera. Our study area consists of three separate thermal areas in the Lower Geyser Basin located along Rabbit Creek, White Creek, and Sentinel Meadows. Students measure the temperature of each hot spring using thermocouples and determine its location using a GPS unit. Baseline temperature data for our study was collected on June 28–29, 2000. In 2002, we began collecting pH data and digital imagery of each thermal feature. On June 26–27, 2002 we revisited the study areas and collected data on about 150 hot springs. Springs in Sentinel Meadows thermal area are consistently the hottest of all the study areas, with temperatures typically ranging from 85–96°C. In general, springs have either remained stable or shown temperature increases of 3–4°C since 2000. A few new springs may have developed in this area. The pH ranged from 6.2–8.7 in Sentinel Meadows and exhibited a positive correlation with temperature. There was no correlation between pH and location or pool size at Sentinel Meadows. The Rabbit Creek thermal area exhibited the greatest range in temperatures of the three study areas, 40–95°C. Overall, about 60% of the springs showed modest temperature increases since 2000, typically between 3 and 7°C. Rabbit Creek has the widest variance in pH of the three study areas (6.0–9.5), but there is no correlation between temperature and pH. Larger pools tend to have higher pH values than smaller pools and there appears to be a geographic pattern of water pH at Rabbit Creek. Thermal features in the White Creek Group range in temperature from 53–95°C. In this group, more springs have shown temperature decreases than increases, although most have remained unchanged since 2000. Temperature decreases range up to 10°C whereas increases were as high as 7°C. The White Creek Group has pH values between 6.3 and 8.9, but most are above 7.5. There appears to be no relationship between pH and temperature, geographic distribution, or pool size. Maps and data tables for this study can be viewed at: <http://oldsci.eiu.edu/geology/camp/YNP/ynpres.htm>.

Project title: Eruption Observation of Selected Remote Geysers

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Objective: To determine interval data for remote geysers at Shoshone, Heart Lake, and Gibbon Geyser Basins.

Findings: At Shoshone Geyser Basin, Double Geyser erupted every 4,703–5,583 seconds (mean = 5,258 seconds) and was both less frequent and less regular than in previous years. Frill Spring remained dormant. A new geyser, informally named "Hydra Geyser" or "The Hydra" exhibited unprecedented activity, which disrupted long-established mineral formations. Eruptions occurred in series, with series beginning every 22–103 hours and including 2–5 brief eruptions spaced at intervals of 1–2 hours. Maximum heights were 8–12 feet from two main and twelve minor vents.

At Heart Lake Geyser Basin, Glade Geyser erupted every 14–26 hours, the means for two different data sets of 10 and 44 intervals being 23 and 24 hours, respectively. This represents increased eruption frequency when compared with data obtained in 2001.

At Gibbon Geyser Basin, Phoenix Geyser, which rejuventated in 1995 following a long dormancy of unknown duration, erupted every 4.4–6.6 hours, with means of 5.4 and 5.3 hours for two data sets of 64 and 203 intervals. Durations were exactly one hour with only a few minutes' variation.

Project title: Geologic Dating and Detailed Mapping of Hydrothermal Features—Phase One, Test and Demonstration

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Objective: New scientific techniques of 14C dating and laser mapping provide opportunities to refine knowledge about the absolute and relative chronologies of the development of hydrothermal deposits related to specific hot spring or geyser systems. This project will apply these techniques as a research demonstration for a subsequent proposal to develop a geologic chronology of the development of Old Faithful geyser. 14C dating of silica-impacted trees and organic matter trapped in sinter deposits can provide both direct and indirect ages of hydrothermal activity. Detailed maps of sinter morphology can be interpreted to develop a relative chronology of hydrothermal system development. The Lower Geyser Basin, Grand Geyser area and Castle Geyser provide opportunities to validate these techniques.

Findings: During the first week of November 2002, mapping and sampling were done in Yellowstone. The park was closed to visitors at the time.

Mapping was done at Castle Geyser. A Callidus <http://www.callidus.de> laser scanner was set up at several stations around the geyser, and a 3-D cloud of points was recorded. These points (approximately 745,000 total) were joined to make a complete scan of the geyser. Interpretation of this scan has begun.

This is the first time such a scanner has been used to study a geyser. The fieldwork successfully demonstrated that the laser system is fully functional at lower temperatures than are claimed by the manufacturer. Daytime high temperatures rose to the mid to upper twenties.

Unfortunately three problems arose. First, despite extensive efforts, it was not possible to link an accurate GPS position with each of the laser points. Second, the vapor cloud rising from Turtle Spring obscured the north side of the geyser, and only scattered data were recorded. Third, software last November did not permit linking 3-D laser-gathered points with imagery. Engineers at Callidus have since addressed this software issue. Sporadic snow showers during morning measurements did not seem to impact the overall quality of the results.

During the laser mapping, eight samples of siliceous sinter were collected from the south and southeast sides of Castle Geyser. The eight samples of sinter were collected to study different sinter morphologies and ages, to support the chronological interpretation of the mapping. No samples were collected from sites that are visible to visitors. NPS personnel supervising the research made photographic documentation of each sampling site. An analysis of these samples by optical and scanning electron microscopy is currently underway.

Trees at three sites were sampled for carbon-14 and tree-ring analyses. The first site was located on the hill east of Grand Geyser, where the trees have been killed by silica spray from the geyser. The second site was in one of the side runout channels of Gem Pool. The third site was northeast of Pink Cone Geyser, in the Lower Geyser Basin. As with collection of sinter samples, tree samples were collected from sites not visible to visitors.

Silicification of the Yellowstone trees will be compared with petrified wood from several other sites around the west, to document any differences that might occur in the mechanisms of silicification by thermal waters and more traditional petrification.

Scientific investigation of the wood samples is currently underway.

Project title: Mapping, Chronology, and Geochemistry of Hydrothermal Explosion Deposits in YNP

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Objective: Hydrothermal explosion craters and associated breccia deposits are commonly observed features in Yellowstone National Park. Visitors to popular thermal areas like Upper and Lower Geyser Basin, Norris Geyser Basin, and West Thumb Geyser Basin often see deep conical pools of thermal water and large rock fragments of explosion breccia littering the landscape. Each of these pools is an explosion crater, and they occur throughout the park at all scales from sub-meter to kilometer diameters. Because hydrothermal explosions can occur at any time, they constitute a potential hazard to visitors in the park. Mary Bay, a 3-km-diameter embayment on the north shore of Yellowstone Lake, is a major hydrothermal explosion crater complex that erupted about 10,000 years B.P. and deposited an apron of explosion breccia for several kilometers around Mary Bay. Other major explosion craters in the park include Indian Pond, Turbid Lake, Duck Lake, Fern Lake, Pocket Basin, Roaring Mountain, The Gap at Norris, and a newly discovered site in the Sulfur Hills. Smaller hydrothermal eruptions, at Biscuit Basin, Porkchop Geyser, Seismic Geyser and other localities have been observed in recent years. Our objective is to use geologic and stratigraphic studies, geochronology (principally 14C analyses of carbon), the new high-resolution aeromagnetic data, seismic data from the monitoring network in the park, sonar imaging in Yellowstone Lake and geochemical, mineralogical, fluid inclusion studies to understand better the mechanisms of hydrothermal eruptions, the causes of such events, regional seismicity, and possible relations to recently discovered regional inflation/deflation cycles ("heavy breathing") in the Yellowstone caldera.

Findings: To date, over 80 samples of hydrothermal explosion breccia have been collected for alteration mineralogy, oxygen isotope, rock magnetic measurements, geochronology, and geochemistry analyses and interpretation. We plan to continue to examine and analyze recent, post-glacial, hydrothermal explosion deposits identified in cores and exposed around Yellowstone Lake, in addition to examining other less studied hydrothermal explosion deposits in the park. Recent field mapping and underwater photographic documentation with the submersible remotely operated vehicle in Yellowstone Lake have identified different areas in various forms of hydrothermal development related to doming. These field observations are enabling a clearer understanding on the mechanisms and physical processes toward formation of these potentially hazardous structures. In 2003, we plan on focusing our field studies on these exposures and underwater sites.

Detailed stratigraphic studies in the Mary Bay explosion breccia deposit have identified at least two large wave deposits below and within the unit that can be traced as far as 5 km north of Yellowstone Lake into the Pelican Valley. The lower unit is 1.5 to > 2 m thick and contains numerous small en echelon faults. We suggest that this sand represents a deposit from an earthquake-generated tsunami-like wave, which in turn triggered the explosion of the 13,000-year-old Mary Bay explosion crater complex. Our studies will continue to evaluate the potential of such event occurring in the near future.

Our work will continue to examine and analyze geothermal vent locations, physical characteristics of the deposits and vents and their distribution and chronology, and analyze stable isotopes and fluid inclusions to determine the deposits' temperature of formation and composition of fluid. We will examine details of these hydrothermal systems and their relation to magmatic activity, faulting, and changes in post-glacial lake levels. We also will apply AVIRIS data in conjunction with the recently acquired aeromagnetic survey of YNP to examine areas in and north of Yellowstone Lake that may be future potential sites of hydrothermal explosions. Geothermal fluid changes that are potentially mineralizing within the 600,000-year-old caldera may reflect contrasting time scales: the inflation/deflation cycles occur on a millennial time scale whereas the hydrothermal explosions occur within minutes. Changes in pressure and flow rate would dramatically change as mineralized geothermal fluids are released and confining pressures drop which may significantly contribute to mineralization. Finally, high-resolution sonar imaging, seismic reflection, and submersible surveys in Yellowstone Lake have identified sublacustrine hydrothermal craters, vents, domal structures, and gas pockets.

Project title: Mapping the Floor of Yellowstone Lake Using High-Resolution Bathymetry, Seismic Reflection, and Submersible Remotely Operated Vehicle

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Objective: Our initial goals of obtaining a high-resolution bathymetric map of Yellowstone Lake and unequivocally characterize many lake bottom bathymetric features such as faults, fissures, slumps, hydrothermal deposits, explosion craters, submerged shorelines, and glacial deposits have been achieved. Subbottom seismic reflection profiles, combined with towed magnetometer data obtained at about 200-m line spacing, have discerned zones of active, present-day geothermal fluid migration through sediments or hydrothermally altered sediments. Our surveys (1999–2002) have identified submerged faults, explosion craters, hydrothermal vents, domal structures, and landslide deposits have improved understanding of the interrelationship of these features, their causes, and influences by deeply circulating hydrothermal fluids.

A next phase is to work with NPS fishery biologists in identifying locations of spawning sites for introduced lake trout. The surveys give an accurate picture of the geologic forces forming Yellowstone Lake and how geology affects the aquatic biosphere. In 2003, we plan to focus on specific sites in Yellowstone Lake using the submersible (ROV) remotely operated vehicle with a sub-bottom seismic profiler on specific sites. Such sites in the lake include a very active hydrothermal area interpreted as an inflating domal structure (the Inflated Plain), several young faults, detached landslide blocks, glacial features, and a few other active hydrothermal areas.

Recent studies show the Yellowstone caldera has cycles of inflation and deflation with an amplitude of 30 meters on a millennial time scale. To evaluate this, submerged and tilted shorelines and sites for sub-bottom profiling and coring must be mapped using modern sonar imaging. Samples obtained will be dated. The underwater geologic history integrated with the exposed shoreline history will help define the chronology and shape of cycles related to inflation and deflation of the Yellowstone caldera, and also how these cycles may contribute to hydrothermal explosions.

Findings: The 1999–2002 high-resolution bathymetric, seismic reflection, and submersible surveys of

Yellowstone Lake revealed a spectacular landscape previously unknown to the world. Large siliceous spires and hydrothermal explosion craters protude into and pockmark the floor of the lake, an area mostly within the 640,000-year-old Yellowstone caldera. In addition to the abundant circular, steep-walled depressions interpreted as hydrothermal explosion craters and the siliceous spires, we identified domal features containing gas (steam?, CO2?) pockets, deformed sediments, and hydrothermal vents, and recent, previously unmapped faults, fissures, slump structures, and submerged older lake shorelines. SEM images of the spires sampled indicate their composition to be predominantly silicified filamentous bacteria with subordinate diatom populations and amorphous silica. The 2002 survey of the South, Southeast, and Flat Mountain Arms expose a landscape dominated by glacial processes.

To complement this work, ground-truthing of the surveyed area, involving a submersible remotely operated vehicle (ROV) with sampling (for solids and fluids) and photographic capabilities is being conducted. Our efforts have produced the following products:

1) A high-resolution bathymetric map of Yellowstone Lake
2) A high-resolution magnetic map of Yellowstone Lake
3) High-resolution seismic reflection profiles
4) Geochemistry and stable isotopic studies of vent waters and deposits from hydrothermal vent sites
5) Thermal probe measurements at thermal vent sites
6) SEM images, mineralogical analyses, U-series dates of collected siliceous spire samples
7) Mineralogical analyses, thin sections, lithologic studies of sublacustrine hydrothermal explosion craters and associated deposits
8) Geochemical and isotopic analyses of lake biota
9) Several manuscripts reporting the results and interpretation of data from the Yellowstone Lake surveys

Future products include:

1) Sampling and analyses of core samples from selected sites in Yellowstone Lake, and possibly Lewis and Shoshone Lakes
2) Fly-throughs of the lake to be shown at geologic exhibits within Yellowstone National Park and on our WEB site
3) Digital data set of bathymetric data
4) 15-minute video describing the survey and discoveries to be shown at visitor centers at Yellowstone National Park
5) All products from this study will be made available to the National Park Service (YNP) as a base in making decisions regarding resource management issues.

HERPETOLOGY

Project title: Amphibian and Reptile Inventory and Monitoring: Greater Yellowstone Network

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Objective: (1) Document amphibian and reptile population distribution and abundance across Grand Teton (GRTE) and Yellowstone (YELL) national parks by conducting surveys in randomly selected watershed units and targeted areas. This work establishes the Greater Yellowstone Ecosystem (GYE) as a USGS amphibian monitoring site in a transect of Rocky Mountain national parks from Glacier National Park to Rocky Mountain National Park and fulfills the goals of the NPS Inventory & Monitoring program. (2) Document the presence of amphibian and reptile species that were known to have occurred in GRTE and YELL based on historic records, or are expected to occur based on habitat and regional occurrence, or which have uncertain status. (3) Continue long-term monitoring of a historically studied Columbia spotted frog population near Yellowstone Lake.

Findings: In 2002, we conducted amphibian surveys in 10 watershed units of the GYE: 6 units in YELL, 3 in GRTE, and 1 in JODR. We surveyed a total of 188 potential amphibian breeding (wetland) sites; 133 sites (71%) were occupied by at least one species of amphibian. In YELL, we surveyed 135 wetland sites and found that 110 of these sites (81%) were occupied by amphibians. Multiple occupied sites were found in every watershed unit surveyed. In YELL (watershed surveys), active breeding by Tiger salamanders was documented at 21 sites; Boreal toads at 6 sites; Boreal chorus frogs at 60 sites; Columbia spotted frog at 28 sites. Results of amphibian surveys of the past three years of surveys provide the first systematically collected data set with which to assess the current distribution and relative abundance of amphibian species in YELL and GRTE. Survey results have been compiled into a relational database that meets the needs of NPS Inventory & Monitoring Program and USGS Amphibian Research & Monitoring Initiative.

We conducted surveys/monitoring at targeted areas for the Boreal toad, an amphibian species of high priority in the GYE. In YELL, we searched 12 previously identified toad breeding areas. Eight of these 12 areas were found to be active in 2002; four had large numbers (>3,000) of tadpoles or metamorphs. We also searched targeted areas for spadefoot and the northern leopard frog but none were found. Targeted reptile surveys documented the occurrence of the Northern sagebrush lizard, Intermountain wandering gartersnake, Valley gartersnake, Bullsnake. Species not found in potential habitat that was searched included the Eastern yellow-bellied racer and Rubber boa.

The area occupied by a historically studied Columbia spotted frog population near Lake–Fishing Bridge is a special study area (“apex site”) within the national USGS-Amphibian Research &

Monitoring Initiative. Intensive amphibian population monitoring is conducted at apex sites. Research was first conducted in this area (referred to as Lodge Creek) in the 1950s, was re-initiated in the early 1990s, and has continued annually since then. The total number of egg masses in the area (at three sites) has declined each year since 2000, from 49–54 in 2000 to 43 in 2001 to 41 in 2002. Larval growth rates were higher and dates of metamorphosis were earlier in 2002 than previously observed. Warm temperatures in 2002 and/or low density of tadpoles may explain the unusual growth rates. In 2002, based on the capture of 85 frogs in early August, we found that <6% of the population of the main study area was in the juvenile life stage, compared to 50% in 2000 and 36% in 2001. This steady reduction of juveniles probably reflects recruitment failures in the drought years of 2000–2001. The Lodge Creek study area is within the zone targeted for wildland-urban interface fuels management by YELL and was designated for protective mitigation measures within sensitive habitat areas.

Project title: Status, Movements, and Habitat Selection in the Tiger Salamander in the Little America Flats Area of Yellowstone National Park, with Implications for Monitoring Studies

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Objective: (1) Find out the current status of tiger salamanders in the Slough Creek area of Yellowstone National Park by comparing current occurrence to occurrence data collected in 1992 and 1993; (2) understand the terrestrial movement patterns of tiger salamanders leaving the breeding pond using radio telemetry; (3) determine if the salamanders exhibit characteristics of a metapopulation in the study area; (4) determine the most appropriate sampling scheme for the population.

Findings: In 2002, we sampled 10 sites that had been previously surveyed in 1992 and 1993 by Steven Hill and Robert Moore of Montana State University. Of these 10, we detected tiger salamander presence at 6 sites, whereas Hill and Moore found tiger salamanders at 7 of the 10 sites. We did not find salamanders at two of the sites that Hill and Moore did, but we detected salamanders at one site that they did not. The two sites where salamanders were not detected in 2002 both had very low water levels, which probably was the major reason no salamanders were found there. We also found tiger salamanders at three of eight sites that we surveyed but were not surveyed by Hill and Moore. We only found signs of breeding (eggs, larvae) at four sites across the area. These results suggest that tiger salamanders are stable across this small area.

We were unable to make any conclusions about salamander terrestrial movement due to the ineffectiveness of radio telemetry. The best transmitter range we were able to obtain was 30 meters, and this was when the antenna was directed straight at the salamander. This was likely due in part to the internal helix antenna of the transmitter and in part to the salamander's underground activity, both of which would decrease the range of the transmitter. We inserted radiotransmitters in eight individuals and were able to relocate only two individuals in the terrestrial environment. Each of these individuals was relocated only once before losing contact. In addition, two individuals were found dead, one due to unknown causes and the other in the digestive tract of a wandering garter snake (*Thamnophis elegans*). The remaining four salamanders were never relocated after leaving the pond site. Of the two salamanders with relocations, one traveled about 50 meters from the pond, and the other moved about 100 meters from the pond. Both individuals were from the same pond and both moved in a northeast direction from the pond towards Slough Creek. In addition, whether these salamanders form a metapopulation is also inconclusive based on these data. Examination of local gene flow may be another method to address population structure, and we will be doing a study in this area this summer investigating this question.

It appears that the best sampling scheme for this area is to survey several ponds, due to the fact that fixed sampling sites may dry out from time and time, and result in no detection even if salamanders are in the area. Additionally, we did not detect tiger salamanders in all wet sites, which further cautions against focusing on only one or two ponds in an area. However, when tiger salamanders were detected at a site, they were usually found repeatedly at that site if funnel traps were used as the primary survey method. This indicates that while several sites should be surveyed in a given area, it is not as important to continually sample a given site to detect the presence of tiger salamanders if trapping is being used and the surveys are conducted in the appropriate season.

Project title: Inventory and Monitoring of Herpetiles on Soda Butte and Cache Creek (and Other Areas Opportunistically)

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Objective: To develop amphibian habitat maps with hyperspectral imagery.

Investigators ground-truthed amphibian habitat maps generated with hyperspectral imagery. Accuracy varied between 75% and 100% for pools with algae, and sedge meadows.

Findings: For more information, please visit <http://earthobservatory.nasa.gov/Study/Frogs/>.

HYDROLOGY

Project title: Monitoring High Frequency Transients in the Hydrothermal System of Yellowstone National Park

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Objective: By recording high-frequency groundwater pressure and temperature changes in Yellowstone's active hydrothermal system we hope to improve our general understanding of the controlling processes in the system.

Findings: On September 7, 2002, a pressure transducer and two temperature sensors were installed in Well Y-7 in the Biscuit Basin parking lot. The transducer was set to record pressure every minute and the temperature at the bottom of the hole, and at a depth of 30 ft is recorded on a data logger every hour. Bottom hole (234.5 feet) temperature was 141.6°C.

Data was recovered in December 2, 2002, and it indicates that the transducer was not functional. The transducer was pulled out of the well for repair, and will be re-installed in the spring of 2003. The data indicates a 1°C-temperature transient between September and December.

Project title: Limnology Laboratory Field Trip: Impacts of Geothermal Inputs on a Stream Ecosystem: the Firehole River

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Objective: The objective of our field trip was to expose students to basic stream sampling approaches and examining how geothermal inputs structure river ecosystems.

Findings: Because the UW/NPS field staion (AMK Ranch) was closed during September 2002, I was not able to take this field trip this year. I do plan to continue these field trips as they are the highlight of the class for the students.

Project title: Rocky Mountain Snowpack Chemistry Monitoring

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Objective: Collect and analyze snowpack and snowmelt runoff for concentrations of chemicals associated with acidic precipitation and fossil-fuels emissions to more clearly demonstrate relation to local emissions sources. Study will build on 10-year dataset of atmospherically deposited chemistry of snowpacks and recent findings linking chemical levels found in snowpacks to snowmachine usage in Yellowstone National Park. Work will be a component of a larger National Park Service grant proposal to fund a combined snowpack/snowmelt and air-quality study planned for FY03.

Findings: Snowpack chemistry results for 2002 indicate consistently higher levels of ammonium (NH4+) and sulfate (SO4–) at sampling sites with heavy snowmobile usage as compared to sampling sites at least 50 meters away from snowmobile routes. Concentrations of NH4+ and SO4– in the snowpacked roadway (in-road) (NH4+, 14.9 microequivalents per liter [ueq/L]; SO4-, 13.4 ueq/L) were nearly twice those off-road at Old Faithful (NH4+, 7.9 ueq/L; SO4–, 5.9 ueq/L). Near the West Entrance, concentrations of those two chemicals in the in-road snow (NH4+, 34.3 ueq/L; SO4–, 22.5 ueq/L) were three to five times those found offroad (NH4+, 10.3 ueq/L; SO4–, 5.5 ueq/L). Along the East Entrance Road, near Sylvan Lake in-road vs. off-road concentrations were similar (NH4+, 4.4 vs. 5.4 ueq/L; SO4–, 5.9 vs. 3.3 ueq/L, respectively).

Regional concentrations were represented at other locations in and near Yellowstone located away from snowmobile use including Canyon, Daisy Pass, Twenty-one Mile and Lewis Lake Divide. In general, ammonium concentrations (average of 5.4 ueq/L regionally) tended to be highest near West Yellowstone (10.3 ueq/L) and Targhee Pass (13.8 ueq/L), and near average elsewhere in Yellowstone. Sulfate concentrations were equal to or lower than the regional mean of 5.9 ueq/L.

Sampling at the sites described for 2002 is planned again for the 2003 snowpack.

Project title: Field Trip to Yellowstone National Park, Water Sampling

Principal investigator: Dr. Jeffrey Rosentreter
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Address: Department of Chemistry
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Pocatello, ID 83209

Objective: World renown Yellowstone National Park offers a unique environment in which one may study many both common, and unusual, natural processes. Spectacular and unique geothermal features of the park including Mammoth Hot Springs have a design largely dictated by natural principles. The picturesque terraced pools are the result of a variety of chemical and physical phenomena. The creation of these and other geochemical features are easily explained through the application of standard environmental chemistry theories. Site examination, both physical and chemical, serve to reinforce these theorems. The identification of various types of geothermal features may also be elucidated using relatively simple chemical investigations. The goal of this project is to examine surface and ground water using field and laboratory methods to systematically identify geothermal characteristics. Topics related to these objectives are listed below:

- Sample Collection:
  - Goal: Small Enough to Transport
  - Large Enough to be Representative
  - Safety Considerations
- Sample Types:
  - i) Grab
  - ii) Composite
  - iii) Integrated
- Collection Procedure:
  - i) EPA-600, Table 1, Collect, Preserve, Fill, Detail, & Record
- Sample Preservation
  - Limited by: 1) Biological Action
  - 2) Volatility
  - 3) Hydrolysis of Chemical Compounds
  - 4) Absorption
- Preservation Aids:
  - 1) Refrigeration
  - 2) Freezing
  - 3) Container Type
  - 4) Limit Input Energy (light)
  - 5) pH Control
  - 6) Chemical Addition
  - 7) Minimize Hold Times
- Geothermal Features
  - 1) Alkaline Systems
    - Calcium Carbonate Basis
    - Mammoth Hot Springs
    - NW Park Area
  - 2) Acid Sulfate Systems
    - Vapor Dominated
    - Mud Volcanoes and Fumarole Areas
    - East Central Park Area
  - 3) Neutral Chloride Systems
    - High Temperature Liquid Dominated
    - Silica Desolvation
    - Geyser and Hot Pool Areas
    - West Central Park Areas

Findings: As listed in previous IARs, surface waters in the sheep eaters cliffs area have to some degree been linked to the spring waters at Mammoth Hot Springs. More recently over the past three years the soil water content at the internal drainage basin located 100 yards north of the Sheepeater Cliffs picnic area have shown steady decreases in pH. The trend most likely can be a result of increasing use of that area by larger animals. Additionally, this may be a result of reduced meteroric water in the area that in turn has decreased arobic respiration in these soils. Barring interference by the ongoing road improvments this area will continue to be monitored on future trips.

Project title: Disturbance Impacts on Stream Morphology, Microhabitats, and Riparian Ecology

Principal investigator: Dr. W. Andrew Marcus
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Address: Department of Geography
University of Oregon
Eugene, OR 59703

Additional investigator: Lorin Groshong

Objective: During 2002, the primary objective of the study was to map the distribution of riparian vegetation types (grass, sedge, rushes, willow, cottonwood, alder, aspen) in areas for which we had remote sensing imagery from 1994, 1995, 1999, 2001, and 2002. A secondary goal was to document plant characteristics that might affect the spectral response of the vegetation and how well it could be mapped using remote sensing.

Findings: During September and October of 2002 we mapped riparian vegetation to imagery in lower Soda Butte Creek, along the Lamar River, lower Slough Creek, and Blacktail Creek near the road. We are presently transferring the field data to remote sensing imagery and stitching together the hundreds of remote sensing images that make up the northern range. Imagery available to us includes: (1) 1994, 1995: 1-m 4-band data from the ADAR5500 sensor for the entirety of Soda Butte and Cache Creeks; (2) 1999: 1-m 4-band data from the ADAR5500 sensor for most major streams along the northern range; (3) 2001: IKONOS data at 1 m for lower Soda Butte Creek; and (4) 2002, 3di 3-m, hyperspectral data for Soda Butte and Cache Creeks and the Lamar River. In addition to mapping the data to the imagery, we have transferred the field data on individual plants to Excel spreadsheets. Analysis of the data has not yet commenced. We anticipate initial results on how well the riparian vegetation can be mapped with remote imagery during late spring to early summer of 2003.

Project title: Dartmouth College Earth Sciences Field Methods

Principal investigator: Dr. Xiahong Feng
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Address: 6105 Fairchild
Dartmouth College
Hanover, NH 03755

Additional investigator: Carl Renshaw

Objective: This is one segment of the three-month course of Field Methods in Geology and Environmental Studies taught by the faculty of Earth Sciences Department of Dartmouth College. The objective for the Yellowstone segment was to teach students a number of field methods used in glacial geology, fluvial hydrology and stream geochemistry.

Findings: We are analyzing the chemistry of Beryl Spring. Because of road construction, we were unable to sample this spring in 2002.

Project title: Reference Reach Measurement

Principal investigator: Mr. Pete Bengeyfield
Phone: 406-683-3966
Address: 420 Barrett St.
Dillon, MT 59725

Objective: Measure physical characteristics (dimension, pattern, profile, floodplain, woody debris, pool type and frequency, chanel stability, streambank erodibility, valley bottom width/gradient) of stream reaches in the Park to use as reference conditions for similar reaches on managed land on National Forests and private lands. Use GIS to obtain physical watershed characteristics (size, geology, slope, aspect, vegetative cover) to aid in comparing wastersheds above selected reaches.

Findings: Measured approximately 35 reaches in YNP during the summer of 2002. These reaches have been combined with approximately 50 others from wilderness or other reference areas on surrounding NF's to form a dataset describing reference conditions. Steamtypes are predominately E's and C's (Rosgen 1996) as these are "response" reaches and thus most likely to show the effects of management.

INFORMATION SYSTEMS

Project title: Science and Scientific Research in Yellowstone National Park: An Internet-Searchable Bibliographic Database

Principal investigator: Ms. Cynthia Kaag
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Email: kaag@wsu.edu
Address: 1316 North Mountain View
Moscow, ID 83843

Objective: This database is intended to facilitate the work of scientists and researchers working in and around the park and is an ongoing project. Currently the database is limited to studies dealing specifically with Yellowstone National Park, with limited material on the entire Greater Yellowstone Area. It is gradually expanding to cover the entire bio-geo-ecosystem.

Besides non-Yellowstone materials, excluded are: articles from general popular magazines, most legislative materials, most sociological materials. Anthropology and archaeology coverage is incomplete.

Citations vary in content depending on type of material and my access to the original. Most have abstracts, many have additional notes, and all have subject headings assigned to facilitate searching for everything on a given topic under one term.

Locations are given only if the item is likely to be hard to find through normal interlibrary loan and document delivery services and if I have actually seen the item at the location noted.

Findings: During the past year some 300 new entries were added, and another 400 updated or expanded.

INVERTEBRATES

PROJECT TITLE: BUTTERFLIES OF YELLOWSTONE AND GRAND TETON PARK (ALSO ODONATA)

Principal investigator: Mr. Richard Lund
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Email: mardell.moore@spl.org
Address: Consultant Services Northwest, Inc.
6521 36th Avenue NE
Seattle, WA 98115-7427

Additional investigator: Mardell Moore

Objective: To produce field guides and other educational materials to the butterflies, dragonflies, and damselflies of Yellowstone and Grand Teton National Parks.

Findings: Fieldwork was conducted for two and one-half weeks from August 14–30. 2002. Duplicate slide photographs taken of butterflies, dragonflies, and damselflies will be sent to the park. Fourteen slides were taken of butterflies; two slides of dragonflies, and ten slides of damselflies. Researches spent many hours in volunteer work this field season in the park. Researchers hauled, split, and stacked wood for two park amphitheaters. There is a need to access more of the backcountry areas of the park in order to complete the fieldwork.

Project title: Respiratory Physiology and Thermal Preference in Thermophilic Aquatic Insects

Principal investigator: Dr. Brent Ybarrondo
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Email: baybarro@adams.edu
Address: Department of Biology
Adams State College
Alamosa, CO 81102

Additional investigator: Lori Ybarrondo

Objective: To understand the degree to which water temperature and dissolved oxygen tension in a highly heterogeneous environment affects respiratory physiology and ecology of thermophilica aquatic insects (Odonata, Coleoptera).

Findings: I was not successful in securing funding for this research during 2002. In fall 2002 a proposal was submitted to the National Science Foundation for funding of this research for the coming three years.

Project title: The Mosquito of Yellowstone National Park, A Study of Their Species and Their Biology

Principal investigator: Dr. Lewis Nielsen
Phone: 801-277-2055
Address: 4835 South 2120 East
Holladay, UT 84117

Additional investigator: James P. Moore

Objective: An ongoing study of the species present and their behavior and biology.

Findings: Observations and collections were made, but none were returned for collections purposes. Reports are in progress.

Project title: Capture and Release Only of Butterflies and Other Insects/Arthropods During Yellowstone Institute Coursework

Principal investigator: Dr. Robert Anderson
Phone: 208-282-2421
Address: Department of Biological Sciences
Campus Box 8007
Idaho State University
Pocatello, ID 83204

Objective: Butterflies were studied on a catch-and-release basis in the northern sector of Yellowstone National Park and its environs during the first week of July 2002. The purpose of the activity was primarily instructional for students enrolled in courses with the Yellowstone Institute, and to obtain anecdotal information on the general diversity and abundance of rhopalocerous Lepidoptera as compared to similar informal knowledge obtained for butterflies in the region in previous years.

Findings: About 20 different species of butterflies representing the families Hesperiidae, Lycaenidae, Pieridae, Satyridae, Papilionidae, and Nymphalidae were either seen or collected and released during the five days of study. A population density study using captured, marked, released and recaptured (then released) specimens of parnassian butterflies in the vicinity of the cabins at the Institute facilility at Lamar suggested no changes from such information collected and reported for this species in previous years, and also indicated these butterlies do not disperse much more than one-quarter mile from their points of growth and development.

LAND USE/FORESTRY

PROJECT TITLE: ANNUAL FOREST HEALTH MONITORING INVENTORY OF WYOMING

Principal investigator: Mr. Michael J. Wilson
Phone: 801-625-5388
Email: mjwilson@fs.fed.us
Address: USDA Forest Service
Interior West Forest Inventory
Rocky Mountain Research Station
507 25th Street
Ogden, UT 84401

Additional investigator: Roger Boyer

Objective: Gather information on the quantity and quality of forest resources, growth, mortality, removals, and forest health.

Findings: Annual Forest Health Monitoring Inventory of Wyoming project is an ongoing natural resource inventory. Results of the inventory are periodically updated and made available at <www.fs.fed.us/rmrs/ogden>.

LICHENS

PROJECT TITLE: RECOLONIZATION BY LICHENS AND MOSSES ON SUBSTRATES BURNED IN THE 1988 FIRES

Principal investigator: Dr. Sharon Eversman
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Address: Ecology Department
Montana State University
Bozeman, MT 59717

Objective: The objectives of the study were to document initial return of lichens and mosses since the 1988 fires in meadows and four forest types (Engelmann spruce, Douglas fir, whitebark pine and lodgepole pine). The substrates examined were burned wood, soil and rock.

Findings: The percentage of burned wood substrates recolonized by moss or lichen or both was highest in Engelmann spruce (81.6%) and Douglas fir sites (80.5%), and lower in lodgepole pine (66.1%) and whitebark pine (62.6%) stands. Moss recolonization on burned wood was significantly greater in the Engelmann spruce sites (64.0%) than in the other forest types (38.9–41.8%). The major recolonizing moss species were *Ceratodon purpureus* and *Bryum caespiticium*. Lichen recolonization on burned wood was highest in spruce sites (64.8%) and lowest in lodgepole pine sites (44.3%). Seventeen lichen species were found recolonizing burned wood, with *Cladonia* spp. (*squamules*, *C. fimbriata*, *C. coniocraea*) the main recolonizers. On soil, *Bryum* spp., *Ceratodon purpureus*, *Polytrichum juniperinum* and *P. piliferum* were the primary mosses, and *Peltigera rufescens* and *P. didactyla* were the primary recolonizing lichens. Most of the burned rhyolite boulders remained uncolonized by lichens or mosses, although *Ceratodon purpureus* was frequently in cracks in rock and around the bases. Scattered areoles of six crustose lichen species were on occasional burned rhyolite, and nine lichen species were on granite that had been burned. A total of 13 mosses were identified in the burned sites. All of the recolonizing lichens are common components of the Yellowstone forests, and most are sorediate. All but one of the mosses were in the YNP herbarium.

MAMMOLOGY

Project title: Black Bear Demographics in Yellowstone National Park: Their Interrelationship to Other Carnivores, Habitats, and Humans

Principal investigator: Dr. Charles Schwartz
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Address: Northern Rocky Mountain Science Center
Interagency Grizzly Bear Study Team
P.O. Box 172780
Montana State University
Bozeman, MT 59717-2780

Additional investigators: Mark Haroldson, Kerry Gunther, Glenn Plumb

Objective: To determine patterns of habitat use, food habits, activity patterns, movements, and home range size for randomly captured black bears.

Findings: These data include information collected by the Interagency Grizzly Bear Study Team (members include U.S. Geological Survey, Yellowstone National Park, Wyoming Game and Fish, Idaho Fish and Game, Montana Fish, Wildlife and Parks, U.S. Fish and Wildlife Service, U.S. Forest Service) for the entire Greater Yellowstone Ecosystem. Data obtained within Yellowstone National Park is not broken out separately.

No additional black bears were captured during the 2002 field season. One female black bear with two cubs-of-the-year was handled in her winter den, and her collar replaced. The GPS collar retrieved from this female collar contained 1,129 locations. The winter den of the remaining male black bear wearing a GPS collar in YNP was found, but the bear was very aggressive, having been rousted by a pack of wolves within a day of our visiting the site, and could not be handled.

Project title: Seasonal Habitat Selection by Bison in Yellowstone National Park

Principal investigator: Dr. Peter Gogan
Phone: 406-994-6989
Email: peter_gogan@usgs.gov
Address: USGS-Northern Rocky Mountain Science Center
Department of Ecology
Montana State University
Bozeman, MT 59717-3460

Additional investigator: Edward M. Olexa

Objective: (1) Document seasonal habitat use by bison throughout Yellowstone National Park (YNP);

(2) identify important characteristics of bison habitat in YNP; (3) develop predictive models of habitat use by bison in YNP; (4) construct spatially explicit models depicting habitat use within YNP during biologically important time periods.

Findings: (1) Eighty-nine bison were captured and instrumented with radiocollars. Nearly 3,000 locations depicting habitat use were obtained. (2) Habitat selection was nonrandom for bison in both the northern and central herds. Significant habitat components differed between herds and among seasons. (3) The relative importance of habitat characteristics varied seasonally as did distributions of predicted use. (4) Data analysis and model development are complete. Manuscript preparation continues.

Project title: Understanding Consequences of Past Management Actions: Genetic Differentiation Within and Among Reintroduced Elk Populations in the Western States

Principal investigator: Dr. Janet Rachlow
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Address: Department of Fish and Wildlife Resources
University of Idaho
Moscow, ID 83844

Additional investigator: Jason Hicks

Objective: Molecular techniques were used to explore partitioning of genetic variance among four reintroduced populations of elk in the western states and the Greater Yellowstone Ecosytem (GYE) source population. The four reintroduced populations of elk examined in our study, include Theodore Roosevelt National Park (TRNP) in North Dakota, Wichita Mountain National Wildlife Refuge (WMNWR) in Oklahoma, Vermejo Ranch in northern New Mexico, and Wallowa/Whitman National Forest (Chesnimnus) in Eastern Oregon. We used molecular genetic techniques to address the following objectives: (1) assess overall levels of genetic variation within four reintroduced populations of elk and the GYE source population; (2) compare levels of genetic diversity among reintroduced populations; (3) assess partitioning of genetic variance and population differentiation between reintroduced populations and the GYE population.

Findings: We examined patterns of genetic diversity in the reintroduced populations described above and their source population (GYE). Tissue and blood samples were collected for genetic analyses from each elk population. DNA was extracted from 20 samples from each of the four reintroduced populations of elk, and we are currently extracting DNA from the Yellowstone source population. DNA was amplified for genetic analyses using Polymerase Chain Reaction (PCR). Five polymorphic microsatellite loci were used to examine the genetic structure of each population examined to date. Microsatellite DNA associated with the primer pairs for each of the five loci was amplified and genontypes were recorded for each individual. Genotypes and extracted DNA from twenty GYE elk were graciously provided by Dr. Gene Rhodes at Purdue University for present analyses involving the GYE source population.

Genetic and statistical analyses for this work are in progress. We anticipate completing the research in December 2003.

Project title: Evolution and Ecology of Vertebrates of Yellowstone National Park

Principal investigator: Dr. Elizabeth Hadly
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Address: Department of Biological Sciences
Gilbert Building
Stanford University
Stanford, CA 94305-5020

Objective: To determine influence of biotic and abiotic factors on the ecology and evolution of the vertebrates of the northern Rocky Mountains. This long-term study includes analysis of morphology, body size, ecology and population genetics of selected species. Complementary studies include the taphonomy of Holocene faunas, and isotopic analyses of bones, vegetation and inorganic material.

Findings: No fieldwork was conducted in Yellowstone during the 2002 field season.

MAPS/CARTOGRAPHY

Project title: Integrated Biogeochemical Database

Principal investigator: Dr. Daphne Stoner
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Address: INEEL Biotechnology, MS-2203
P.O. Box 1625
Idaho Falls, ID 83415-2203

Objective: Develop integrated GIS data system for mapping microbial biodiversity and associated geochemical and geological habitat.

Findings: No sampling activities were conducted during 2002.

Project title: Remote Sensing-Based Geostatistical Modeling for Coniferous Forest Inventory and Characterization

Principal investigator: Dr. Mark Jakubauskas
Phone: 785-864-7316
Email: mjakub@ukans.edu
Address: 2335 Irving Hill Road
Lawrence, KS 66045

Additional investigators: L. Monika Moskal, Edward A. Martinko, Kevin P. Price

Objective: The goal of this research is to develop, test, and demonstrate an integrated remote sensing and geostatistical approach for the analysis of forest canopy structure, secondary forest regrowth, and forest fire history that takes advantage of the spectral and spatial correlation of ground phenomena and remotely sensed information. The project has four objectives: (1) development of geostatistical models for forest biophysical parameters (height, density, basal area, leaf area index, and biomass) using multi-scale satellite imagery and field data; (2) calibration and verification of the models by field data and statistical means; (3) testing the models in two specific forest characterization and inventory applications, (forest cover type mapping and insect damage assessment); and (4) dissemination of the algorithms and procedures to the user community via on-line tutorials and software modules. Initial model development will focus on the lodgepole pine forest of the Greater Yellowstone Ecosystem.

Findings: A short (five-day) field season was conducted in September 2002 in the western part of the Yellowstone Central Plateau in order to acquire final field data for verification of remote sensing-based geostatistical models of forest structure. The principal focus of the 2002 fieldwork was on regenerating lodgepole pine forest stands in the Lower and Upper Geyser Basin area. Plots were sampled for number, size, and density of seedlings in several height classes. A number of digital photographs were taken of live and dead standing trees and deadfall for use as inputs to visualizations of research results created using Visual Nature Studio animation software. Digital "fly-overs" and animated forest change movies were created using these real-life models and digital airborne and satellite imagery as inputs.

MICROBIOLOGY

Project title: Determination of In Situ Growth Rates of Filamentous Sulfur-Oxidizing Bacteria in a Hydrothermal Vent Field in Yellowstone Lake

Principal investigator: Dr. Gill Geesey
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P.O. Box 3520
Montana State University
Bozeman, MT 59717-3520

Objective: To establish the relationship between filamentous bacterial growth rate and hydrogen sulfide concentration at sediment/water interface in Yellowstone Lake.

Findings: During July–September of 2002, stainless steel coupons were deployed by SCUBA at a previously sampled site in Mary Bay, Yellowstone Lake, in order to determine whether a relationship could be established between growth rates of sessile filamentous sulfur-oxidizing bacteria and ambient hydrogen sulfide concentrations in the surrounding water. Coupons were suspended by a coupon holder either in or immediately above the orifice of a hydrothermal vent emitting hydrogen sulfide-containing fluid. One set of four coupons was suspended directly in the vent, where coupon surfaces were exposed to hydrogen sulfide concentrations ranging from 145–486 mg/L. Another set of four coupons was positioned in the flow path of the venting fluid at the sediment-water boundary where hydrogen sulfide concentrations ranged from 60–255 mg hydrogen sulfide /L water. Another set of four coupons was positioned in the flow path of the venting fluid 3 cm above the sediment-water boundary where hydrogen sulfide concentrations ranged from 5–75 mg hydrogen sulfide /L water. Another set of four coupons was positioned 2 cm above the sediment-water interface at an adjacent site with no visible venting fluid. At 1-, 3-, 6- and 12-day intervals, a sample of water adjacent to each set of coupons was collected by SCUBA and the hydrogen sulfide concentrations determined on shore. At the same time these water samples were collected a coupon from each set was transferred to a screw-capped plastic tube, the tube brought to the surface and fixative added to preserve the bacteria attached to the coupon. Following transport to our laboratory at MSU, coupon surface-associated bacteria were stained with DAPI, examined by epifluorescence microscopy, and the length of the bacterial filaments and number of cells per filament recorded and converted to specific growth rates based on the time elapsed since coupon deployment. A positive correlation was obtained between the number of cells in the largest filament associated with each coupon at each sampling period and hydrogen sulfide concentration measured in the surrounding water at the end of that period. The best linear correlation ($R= 0.84$) was obtained after a three-day incubation period. The equation derived from a linear relationship between hydrogen sulfide concentration and the number of cells in the largest filament on coupons incubated for a three-day period predicts that the number of cells produced in a filament over a three-day period can be estimated by dividing the total hydrogen sulfide concentration in the surrounding water by 5.6. These results also suggest that growth rates of sessile filamentous sulfur-oxidizing bacteria are likely controlled by the hydrogen sulfide concentrations during the summer months at this site.

Project title: Diversity and Habitat Range of Sulfate Reducing Microorganisms

Principal investigator: Dr. David A. Stahl
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Civil Environmental Engineering
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Box 352700
Seattle, WA 98195-2700

Additional investigators: Heidi Gough, John Koke, Anne Bernhard, Jesse Dillon,
Nicolas Pinel, Paul Berube

Objective: Our research at Yellowstone National Park has focused on better defining the diversity of sulfate-reducing bacteria along environmental gradients of pH and temperature. Organisms having the capacity to respire sulfate drive a key step in the global cycling of sulfur and are likely an important biological presence in many of the sulfur-rich geothermal areas within Yellowstone National Park. A long-term objective is to better define the environmental limits of dissimilatory sulfate reduction. Our primary method of assessing population diversity has been comparative sequence analysis of the highly conserved dissimilatory sulfite reductase (DSR) gene. This gene can be selectively amplified from DNA recovered from site material using PCR, as reported by our research group (Wagner, Roger et al. 1998; Minz, Flax et al. 1999). Comparative sequencing of cloned DSR genes avoids the usual biases associated with culture-based methods of characterization. We complement this molecular characterization with on-site activity measurements and also use more traditional culture-based methods to evaluate cultivable sulfate-reducing bacteria.

Findings: No Activity in Yellowstone National Park during 2002. Data analysis in progress in preparation for publication.

Project title: Isolation and Characterization of Thermophilic Viruses from Yellowstone National Park

Principal investigator: Dr. Mark Young
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Address: 199 ABS Facility
Montana State University
Bozeman, MT 59717

Additional investigators: Jamie Snyder, Sue Brumfield, George Rice, Gerard Sellek, Josh Spuhler, Debbie Willits, Blake Wiedenheft

Objective: The objective of this research is to isolate and characterize thermal viruses from YNP. We are currently looking at the diversity of Sulfolobus viruses and how they might change with the changing geochemistry of the hot springs. We are also looking at the isolation of new viruses from Sulfolobus that have never been discovered before.

Findings: We have identified and isolated several new viruses from YNP and are currently conducting research on the genome and the structure of these viruses. The diversity of Sulfolobus viruses is greater than we anticipated, but as of yet are unable to link geochemistry data to the changing viral population, more data is needed.

Project title: Research Experience for Undergraduates: Yellowstone National Park Field Trip

Principal investigators: Dr. Anne Camper
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P.O. Box 173980
Montana State University
Bozeman, MT 59717

Additional investigators: Melissa Cahoon, Darla M. Goeres

Objective: The Research Experience for Undergraduates program at the Center for Biofilm Engineering, Montana State University, recruited talented students in various science, math and engineering disciplines to spend 10 weeks in Bozeman conducting biofilm research, learning effective technical communication skills and debating ethical issues that arise in technical fields of work and study. Yellowstone National Park served as the perfect location to debate the ethics of harvesting microorganisms from natural environments. The students spent two days in Yellowstone observing wild type biofilms and discussing current biofilm research being conducted in the park.

Findings: The trip to Yellowstone increased the students' appreciation for field research. Viewing biofilm in a natural environment demonstrated the complex ecology associated with a living biofilm better than any bench-top laboratory system. The students left Yellowstone with a better understanding of the issues surrounding research in a national park.

Project title: Bacteria Living at Low pH and High Temperature

Principal investigator: Dr. Rick Bizzoco
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Address: San Diego State University
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Department of Biology
San Diego, CA 92182

Objective: The objectives include the discovery, isolation, and characterization, including phylogenetic (16S rDNA) characterization, of unknown genera of microorganisms living at low pH (< pH 3) and high temperature (>70°C).

Findings: We examined samples microscopically from acid hot springs at several sites, including Amphitheater Springs, Frying Pan Spring, Mud Volcano, Norris Junction, and Sylvan Springs. We focused our study on Evening Primrose Spring (Sylvan Springs) which changed in color from gray to pale blue and increased in pH over time from 1 to 3 to 6.5. We isolated several thermoacidophiles on agar plates at pH 3; 70°C and pH 5; 65°C , examined the pH and temperature optima of enrichments by generation time, and are beginning 16S rDNA sequencing of the isolates.

In a separate study, we developed methods for attachment and fixation of extremophiles for scanning electron microscopy and X-ray microanalysis. We used isolates from Amphitheater Springs for this study. We continued our characterization of a new genus (based on 16S rDNA sequence) isolated from Amphitheater Springs.

Project title: Characterization of the Microbial Rhizosphere Population of Acid and Thermotolerant Grasses Associated with Hot Springs and Microbial Diversity in Thermal Soils in YNP

Principal investigator: Dr. Timothy McDermott
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Address: Thermal Biology Institute
Montana State University
Bozeman, MT 59717

Additional investigator: William Inskeep, Jesse Christiansen, Seth D'Imperio, William Franck, Jon Wraith, Lina Botero, Paul Messner

Objective: The objectives of this ongoing study are to isolate novel thermophiles and characterize the microbial diversity occurring in geothermally heated soils and springs in Yellowstone. Our work continues to focus on microbes occurring in the rhizosphere of thermotolerant plants in thermal soils, microbes in soils but not associated with these plants, and thermophilic microbes in nearby springs. The methodology employed includes various traditional and nontraditional cultivation approaches, as well as various molecular approaches. For the latter, we are currently focusing on the 16S rRNA gene as a means of comparing diversity between communities and for characterizing phylogenetic distributions within communities. Most soil work utilizes reverse transcriptase and RNA.

Findings: Molecular-based (i.e., 16S rDNA cloning) work has discovered novel archaea inhabiting high temperature soils. These archaea are known only as 16S rDNA PCR clones ad, but we are currently attempting to isolate these novel organisms.

We have isolated several organisms having phylogenetic signatures that appear novel relative to those available in public databases. Physiologic and structural characterizations of one of these isolates has shown it to be the first reported gram positive microbe that phylogenetically falls into the Green Non-sulfur phylum.

We have begun characterization (in collaboration with Paul Messner, Universitaet fuer Bodenkultur Wien, Austria) of another thermophile that is 95.1% similar to *Bacillus stearothermophilus*.

Other cultivation work includes the isolation of what appears to be a novel species of *Hydrogenobaculum*. Characterization of this organism focuses on its role in arsenite oxidation in the acid-sulfate-chloride type springs that are found throughout Norris Basin. Effects of ferric iron and hydrogen sulfide were also assessed in terms of overall influence on arsenic redox cycling and compared to microbial based redox transformation activity.

Other work has discovered multiple clone types of *Hydrogenobaculum*-like and *Desulfurella*-like organisms in acid-thermal springs and hydrogen sulfide micro vents in Norris Geyser Basin. This work is ongoing and forms the basis for a National Science Foundation Microbial Observatory.

Project title: Phylogenetic Analysis of High-Temperature Ecosystems

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Additional investigators: J. Kirk Harris, Alicia Berger, John Spear, Scott Dawson, Jeff Walker

Objective: Ongoing research continues to focus on the survey of microorganisms in Yellowstone microbial ecosystems with varying solution chemistries. We have been measuring hydrogen concentration in the bulk aqueous phase to determine the variability in H2 concentration in the park's hot springs. Small samples of biomass (1–10 grams) are obtained, and brought back to the lab for analysis by a molecular approach, rather than the traditional methodology of culturing. The molecular approach is based on cloning and sequencing of the small sub-unit ribosomal gene (16S rRNA gene) to determine the microbial composition of these ecosystems. Ongoing studies include analyses of sub-aqueous and sub-aerial systems for bacterial, archaeal, and eucaryal life. We are also looking at the microbial communities, by this same approach, that live within the pore spaces of rocks, termed endoliths, from hotspring locations around the park.

Findings: Work from 1999 and 2000 on Well Y-7 in Biscuit Basin, was published in Yellowstone Science in the Fall 2002 issue, V. 10 (4), pp. 15–21. We found that the sub-surface of Biscuit Basin has a varying temperature of its hot waters over the course of a year. We also found that the Well is rather devoid of life along its 250-foot length and that it has a thermal gradient of 50°C at the surface to 135°C at the bottom. We are currently collaborating with Shaul Hurwitz of the U.S. Geological Survey who has initiated a long-term data-logging study of Well Y-7.

In 2001–02 we measured the bulk aqueous phase hydrogen concentration at a number of hot springs in the park. We found high nM concentrations of H2 at a number of locations, indicating that hydrogen, rather than sulfur, probably drives primary productivity in this geothermal ecosystem. This is supported by the molecular microbial studies done within the park, where the overwhelming number of organisms utilize H2 as the basis for their metabolisms. More sites await analysis and we plan to do more fieldwork in 2003. A manuscript on this work is in preparation.

Work from 1998 and 1999 on the formation of geyserite within the park and its associated microbiota has been completed. We see again, an extreme amount of microbial diversity, and a dependence on hydrogen. This work, with lead author Carrine Blank, was published in *Applied and Environmental Microbiology* in October 2002, V. 68 (10), pp. 5123–5135.

Project title: Energy Availability for Photosynthesis-Independent Microbial Ecosystems in YNP

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Objective: (1) Assess the level of chemical free energy available to anaerobic microorganisms in the effluent of springs representing a broad variety of temperatures and chemical compositions. We hypothesize that fluids transiting reducing host-rocks will contain levels of H^2 sufficient to support metabolism by methanogenic or sulfate-reducing microorganisms. We further hypothesize that springs with low flow rates may allow for more complete interception of upwelling substrates by subsurface communities; under these conditions, fluid emanations at the surface should contain H^2 concentrations close to the minimum biologically-useful level (predictable as a function of temperature).

(2) For springs with chemical compositions capable of supporting anaerobic metabolism, perform a phylogenetic characterization of microorganisms contained in effluent from the deeper, anoxic portions of the springs. We hypothesize that, where a particular type of anaerobic metabolism (e.g., methanogenesis) is energetically feasible, corresponding sequence types will be recovered in the upwelling fluid, as small quantities of organisms from within the anaerobic zone are sloughed off and swept into the water flow.

(3) For 2–3 springs where chemical and phylogenetic analysis are consistent with the presence of lithotrophic communities, use geochemical and stable isotope analyses to characterize the specific types and rates of metabolism attributable to subsurface organisms. We hypothesize that the presence and activity of subsurface microbial communities will be detectable in the chemical and, particularly, isotopic composition of substrates and products associated with the inferred metabolism (e.g., concentration and 13C content of methane in springs where energetic and phylogenetic analyses infer the presence of a deep methanogen population).

Findings: Fieldwork during the first year of the project was restricted to two days due to external time constraints. Activity during this time consisted primarily of field testing a new methodology for determination of dissolved hydrogen and methane concentrations in hot spring waters. A total of five springs in the Firehole Loop, Rabbit Creek, and Upper Geyser Basin areas were sampled and assayed for dissolved oxygen, hydrogen, methane, carbon dioxide, sulfate, and hydrogen sulfide. Temperature and pH determinations were also made on these springs, and water samples were filtered for later determination of microbial community composition.

Hydrogen concentrations in gas bubbles emanating from these springs varied from approximately 20–2,000 ppm. The highest value (indicating the most energy potentially available to microorganisms) was observed in a small spring near black sand pool. Bubbles from this spring also contained the highest levels of methane, at approximately 20,000 ppm. Combined, these data are consistent with (though not proof for) the presence of a community of methanogenic organisms at depth in this spring. Future work will focus on more intensive characterization of this spring with respect to isotopic composition of methane (which can help to delineate between biotic and abiotic sources) and microbial community composition.

Project title: Arsenic Biogeochemistry in Yellowstone National Park

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Additional investigators: Richard E. Macur, Erica K. Miller

Objective: (1) Determine microbially mediated rates of As(III) oxidation in acid-sulfate-chloride springs in YNP, with primary focus on the Norris Geyser Basin. (2) Evaluate the diversity, distribution and metabolism of chemolithoautotrophic microorganisms inhabiting acid-sulfate-chloride springs. (3) Characterize relationships among As, S and Fe aqueous geochemistry, solid phase formation and specific microbial populations associated with different geochemical zones.

Findings: Our work during the last year focused on several additional acid-sulfate springs found in the Hundred Springs Plain of Norris Geyser Basin, similar in composition and appearance to our original sampling site at Spring No. NHSP106, thermal inventory of YNP (44 43'54.8"N 110 42'39.9"W). At the point of discharge, these springs have a pH of ~3.1, temperatures ranging from 65–85°C and contain approximately 1 mM SO4, 60 uM H2S, 60 uM Fe(II), 30–60 uM As(III) and an ionic strength of 20 mM (primarily Na and Cl). Arsenite (As(III)) is often the predominant valence state at the point of discharge, but is rapidly oxidized to arsenate (As(V)) during transport in shallow surface water. These springs exhibit a distinct sequence of well-separated microbial mats covering the spring floor in both longitudinal and lateral directions. During 2002, our efforts were focused on thorough analytical characterization of geothermal waters as a function of distance from geothermal source, and corresponding molecular analysis of bacteria and archaea inhabiting different geochemical zones.

Specifically, we have investigated geochemical processes and associated phylogenetically-defined (16S rDNA) microbial populations important in the formation and colonization of elemental S and Fe-oxyhydroxide "microbial mats" lining the shallow channel floors. Within several meters after discharge the spring bottoms are dominated by yellow mats containing predominately elemental So. Immediately following the zone of S deposition, extensive brown mats are found across a temperature range of 50–65°C. Analytical characterization of these solid phases using synchrotron-based x-ray absorption spectroscopy (XANES/EXAFS), scanning and transmission electron microscopy and x-ray diffraction (XRD) reveal a highly filamentous microbial mat dominated by an As(V)-rich Fe(III)-oxyhydroxide phase (As:Fe mole ratio = 0.67) that is essentially amorphous to electrons and x-rays. The presence of As(V) in this phase is consistent with rapid microbially-mediated oxidation of As(III) to As(V) observed in the aqueous phase. The oxidation of Fe(II) and subsequent formation of Fe(III)-oxyhydroxide sheaths surrounding microbial filaments suggest the importance of Fe(II)-oxidizing microbial populations in the formation of this phase.

We have also investigated the associated phylogenetically-defined (16S rDNA) microbial populations potentially important in the formation of these microbial mats. Microorganisms detected as a function of distance from source include *Stygiolobus*, *Caldococcus*, *Hydrogenobaculum*, *Desulfurella*, *Metallosphaera*, *Meiothermus*, *Thiomonas*, and *Acidimicrobium*-like populations. This sequence of microbial populations may be defined in part by decreases in temperature from ~ 80–50°C, but is also closely linked to geochemical cycling of S, As and Fe as a function of distance from source discharge. The role of specific bacterial and archaeal populations in the oxidation of S, Fe and As is the subject of our continuing effort to understand linkages among microbial populations and geochemical processes in acid-sulfate-chloride geothermal springs. We are planning on a productive field season in 2003 focused on identifying specific geochemical attributes associated with the diversity and distribution of specific microbial populations in Norris Basin and several similar acid-sulfate springs in other locations of YNP.

Project title: A Survey of *Pilobolus* from Yellowstone National Park

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Objective: (1) To determine what species of *Pilobolus* can be found in Yellowstone National Park; (2) to utilize morphological characteristics and molecular techniques to identify isolates of *Pilobolus*; (3) to correlate contrasting morphological characters with DNA sequences from various isolates; (4) to characterize isolates from Yellowstone using molecular techniques to determine relationships between or among the various morphological taxa; and (5) to determine whether morphological similar isolates are genetically different individuals or are clones of one another.

Findings: During 2002 isolates of *Pilobolus* were collected in Yellowstone National Park during July. These isolates were obtained from dung samples from bison, mule deer, and elk. Dung collections were made in Sentinal Meadow, north of Old Faithful, west of Madison Junction, north of Hayden Valley, north of Grant Village and near the Upper Falls of the Yellowstone. All fungal isolates have been maintained in the laboratory at Indiana University East are being used to develop techniques to distinguish among the species of *Pilobolus*. As these techniques are perfected they will be used to complete this study. Substantial progress was made in the past year using molecular techniques and DNA sequencing to resolve evolutionary relationships in *Pilobolus*.

Project title: Molecular Ecology of Photosynthetic Hot Spring Bacteria That Resemble *Heliothrix Oregonensis*

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Additional investigator: Daniel Lodge

Objective: There were three objectives to our study this year: (1) to collect and chemically characterize geothermal groundwater supporting four red layer communities (Hillside, Fairy, Spray, and Imperial) we have previously described; (2) to collect and chemically characterize mat samples from all of the above sites, comparing this information with obtained water chemistry data; (3) to survey and collect additional red layer communities at Joseph's Coat, Pununtpa, and Hot Springs Basin. This was to be done in the context of a Yellowstone Institute course (lead by Dr. Foley).

Findings: In terms of goals 1 and 2, we collected and chemically analyzed water (6L per site) and mat samples (1 cm^3 per site) from the four sites described. These data have been placed in our new Red Layer Microbial Observatory (RLMO) on-line database. To our suprise, we observed site-specific variation in many chemical signatures that may explain observed genetic variation. We are excited about these preliminary data not only for this reason but also because we will be using this information to design site-specific media that may provide the key to culturing the red filaments. Repeating these chemical surveys will be essential in 2003, both for publication reasons and for media design issues.

In terms of goal 3, Danny Lodge collected mat samples from Joseph's Coat and Pununtpa Springs but, owing to a demanding itinerary, Hot Springs Basin was cut from the Yellowstone Institute course. We are currently performing molecular studies on all samples and developing a manuscript that compares two Joseph's Coat sites over two years.

Project title: Isolation of New Hyperthermophiles and Investigations of Hyperthermophilic Biotopes

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Objective: Isolation and characterisation of new hyperthermophilic bacteria and archaea and investigations of hot biotopes.

Findings: The existence and characterization of the first isolated acidophilic Hydrogenobacter relative from YNP has been published recently. From the samples taken in 2001 at Obsidian Pool, an anaerobic continuous flow fermentor has been established in our lab. It is operated at 85°C and harbours a mixed culture of hypertermophilic microbes. By ssrRNA gene analyses, we could identify a novel group of the phylum Nanoarchaeota growing within this fermentor. This result was published recently. In addition, the fermentor exhibits a strong ssrRNA signal of the Korarchaeota, a novel group of archaea with so far unknown properties and which we want to characterize further.

Project title: An Analysis of Soil Microbial Community Structure in an Evolving Thermal Soil Environment

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Additional investigators: William Franck, Seth D'Imperio, Lina Botero, Jon Wraith, Corrine Lehr

Objective: The objective of this study was to characterize changes in the microbial community structure resulting from a naturally geothermal expansion event.

Findings: In this study, microbial species diversity was assessed across a landscape in Yellowstone National Park where an abrupt increase in soil temperature had occurred due to recent geothermal activity. Soil temperatures were measured and samples were taken across a temperature gradient (35–65°C, at 15 cm depth) that spanned geothermally disturbed and unimpacted soils; thermally perturbed soils were visually apparent by the occurrence of dead/dying lodgepole pine trees. Changes in soil microbial diversity across the temperature gradient were qualitatively assessed based on 16S rRNA sequence variation as detected with denaturing gradient gel electrophoresis (DGGE) using both rDNA and rRNA as PCR templates, and primers specific for Bacteria or Archaea. The impact of the major heating disturbance was apparent in that DGGE profiles from heated soils appeared less complex than the unaffected soils. Phylogenetic analysis of a bacterial 16S rDNA PCR clone library from a recently heated soil showed that a majority of the clones belonged to the Acidobacterium (51%) and Planctomyces (18%) divisions. Agar plate counts of soil suspensions cultured on dilute yeast extract and R2A agar media incubated at 25°C or 50°C revealed that thermophile populations were 2–3 orders of magnitude greater in the recently heated soil. A soil microcosm laboratory experiment simulated the geothermal heating event. As determined with both RNA- and DNA-based PCR coupled with DGGE, changes in community structure (marked change in DGGE profile) of soils incubated at 50°C occurred within one week and appeared to stabilize after three weeks. The results of our molecular and culture data suggest that thermophiles or thermotolerant species are randomly distributed in this area within Yellowstone National Park and that localized thermal activity selects for them.

Project title: Microbial Biotransformations and Ecology

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Additional investigator: Andrew E. Laursen, Rian Grant, Sophia Dore

Objective: To isolate microorganisms with unique metabolic activities allowing for the transformation of C-1 compounds, polycyclic aromatic compounds, and related products from the petroleum industry.

Findings: We characterized two unique bacteria previously isolated from thermal features in Yellowstone National Park that are capable of growth using methane as a sole source of carbon and energy. These organisms were capable of growth on methane under thermotolerant or thermophilic conditions. These organisms grew best on nutrient agar containing other forms of organic carbon indicating that methane is not a preferred substrate. Sequencing of 16S ribosomal DNA suggests that one of these isolates was most closely related to members of the genus *Comamonas*, and the other was most closely related to members of the genus *Burkholderia*. Members of these genera commonly oxidize a wide variety of small organic compounds due to low substrate specificity of hydroxylase enzymes. Metabolism of methane is most likely the result of this low specificity. These isolates could have applications in the removal of methane or degradation of organic contaminants such as trichloroethylene at high temperatures. Two manuscripts detailing these and previous findings are in preparation.

Project title: Development of Harsh Environment Biosensors

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Objective: The objectives of this study include isolating and characterizing microorganisms from a variety of hot spring environments, screening these organisms for useful enzymatic activities, and purifying and characterizing enzymes obtained from these organisms.

Findings: Water, sediment, and fungal mat samples have been collected from Octopus Spring, spring LNN2, Firehole Spring, Twin Butte Vista Spring, hot lake, Bathtub Spring, Son of Green Dragon, Yellow Funnel, Black Hermit Caldron, and Black Pit. An isolate identified as *Thermus brockianus* was obtained from spring LNN2 that had high levels of catalase activity. Catalase was purified and characterized from this organism. The catalase was found to be one of the most thermal and alkaline stable enzymes reported to date. The enzyme also had properties never before reported in catalase enzymes. Results from this study were presented at the American Society for Microbiology annual meeting and the American Institute of Chemical Engineers annual meeting. We are currently working to obtain bacterial isolates capable of growth at pH 3 and will start screening these organisms for the ability to degrade hemicellulose.

Project title: Ecology of Phototrophs in Extreme Environments—Thermal and High Iron

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Objective: To understand the interactions of phototrophic microorganisms with their environment, especially with iron. We are seeking to understand the effects of microorganisms and their photosynthetic activity on iron oxidation and mineralization processes in hot spring microbial mats. We are also seeking to understand the effects of iron on the microorganisms. In this complex association, the role of other chemical species will also be studied. An overarching goal is to understand potential biosignatures that may be preserved in the iron geological record on Earth such as in Banded Iron Formations. Biosignatures associated with iron deposits could also be useful in the search for evidence of past life on Mars.

Findings: During summer and fall our group made two major and four shorter trips to Yellowstone. The major trips were in June and July and involved multi-faceted studies at Chocolate Pots Hot Springs and a more limited study at Octopus Spring.

At Chocolate Pots we are studying chemical and isotopic variations, early mineralization and fossilization processes, and metabolic activity of phototrophic microbial mats. A detailed contour map at 0.5 m resolution was constructed of the spring area at Chocolate Pots so that we could precisely identify all sampling sites.

Water and iron oxide samples were collected from five vents at the Chocolate Pots Hot Springs site, in order to make an initial assessment of the variability in their chemical and isotopic composition. These data are being collected to understand how oxidation of iron, under natural conditions, affects the composition of fluids and associated mineral deposits, and where the metals in these fluids originated.

The preliminary chemical and isotopic information that has been collected on samples indicate the following: (1) The strontium isotope composition of hydrothermal fluids is an exact match to the strontium isotope composition of the Lava Creek Tuff, the predominant rock type at Chocolate Pots. This observation may imply that alteration of the Lava Creek Tuff supplied most of the metals in the Chocolate Pots hydrothermal fluids. (2) Iron oxide from different sites at Chocolate Pots has variable Fe isotope compositions. The Fe isotope variations found at this site are comparable in magnitude to the variations found in Archean age (>2.5 billion year) iron formations, which is the source of iron ore for nearly all industrial iron. The mechanisms that control Fe isotope compositions may be a combination of oxidation of Fe, precipitation of iron from the fluid, and reaction of precipitated Fe with pore fluids. Similar mechanisms may have been important in the formation of Archean age iron formations. Additional fieldwork at this site will be done to understand what processes control this variability in Fe isotope composition.

Samples of mat and associated sediments were collected and returned to the lab to study structural preservation and mineral deposition. Early mineralization studies showed mineral encrustation of microbial mat components with ferrihydrite. Deposition of colloidal silica and iron silicates on the cells was also detected. The main mineral within all the living mats was ferrihydrite. Ferrihydrite, goethite, and siderite were also observed in non-mat bearing sediments.

The biological studies focused on the higher temperature mats at 50–54°C. Voltammetric microelectrode studies were done in situ to assess the impact of photosynthetic metabolism on the distribution of Fe(II), Mn(II), hydrogen peroxide, sulfide and oxygen within the mats. The pH was around 6 throughout the mat. No sulfide was detected. The profiles showed a narrow band of light-dependent oxygen production in the top 1.5 mm of the mat. Peroxide also accumulated in the light at the same depths as oxygen. High levels of reduced iron present in the vent water were oxidized in the zone of oxygen and peroxide accumulation showing the dependence of the oxidation on photosynthetic activity. In the dark, oxygen and peroxide levels fell to zero. Iron remained high in the dark. Mn was surprisingly high in these mats. It is clear that photosynthetic activity has a major impact on iron levels in the mat. Excised samples were taken back to our lab and it was found that reduced iron stimulated photosynthesis. Similar samples from Octopus Spring, which lacks significant levels of iron, showed no stimulation of photosynthesis by iron.

Project title: Guide to the Microbes of Yellowstone National Park

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Additional investigators: Brett L. Dicks, David Patterson, Joan M. Henson

Objective: To produce a highly illustrated book featuring microorganisms from some of YNP's brightly colored mats and streamer communities. The book will include landscape photos and over 200 micrographs of microbes found in the park.

Findings: All sampling was completed, September–October 2002. Specimens were collected, photographed and identified. We are currently writing the text for the book to be published in 2004.

Project title: Survey of Naegleria

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Objective: Identification of thermophilic amoebae using molecular biological techniques to rapidly survey for the presence of pathogenic Naegleria in places where people swim and soak in thermal waters (legally or illegally) in the park. These amoebae can pose substantial risks to humans.

Findings: Sampling is complete and analysis of data is continuing. Twenty-four sites were sampled and tested. Ten sites tested positive for Naegleria (Boiling River, Nymph Creek, Hillside Springs, Seismic Springs, Bathtub, Madison Campground, Mallard Lake Trail, Terrace Springs, and Huckleberry Springs and Polecat Creek, GTNP).

Project title: Analysis of a Eukaryotic Microbial Mat Community Across Environmental Gradients in a Thermal, Acidic Stream

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Objective: Two Nymph Creek sites, defined in terms of differing light, pH, and temperature, are being extensively monitored over diurnal and seasonal time periods. Contemporary analyses, including microscopy, and rRNA sequencing are being used to document the microbial diversity of the creek and for analysis of the algal mat at both sites.

Findings: Research is ongoing.

Project title: Effects of UV Radiation, Desiccation, and Heavy Metals on the Photosynthetic Microorganisms of Hot Springs and Associated Sediments

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Additional investigators: Erich Fleming, Tracy B. Norris

Objective: A) For the field season 2002 in YNP, one of the objectives was to collect and bring into culture as many cyanobacteria and microalgae from terrestrial mats or crusts as possible. The principal goals that frame this research are to ascertain the community composition in these periodically desiccated habitats by molecular means and to determine the desiccation tolerance of these microorganisms after they have been brought into culture.

B) The other research project concerns *Cyanidium* and relatives (unicellular red algae that live in thermal, acidic environments).

(1) Characterize culture isolates to collect physiologic and phylogenetic data to establish the genera and species that make up the *Cyanidium* complex and to distinguish them from other thermo-acidophilic eukaryotic algae.

(2) Determine if environmental features (e.g., heavy metals, pH, temperature, solar irradiance, competition, desiccation) are correlated with specific *Cyanidium* ecotypes within the various thermo-acidic habitats.

Findings: A) The work with cyanobacterial crusts is still in a preliminary stage, and most of the work currently involves experiments with culture isolates with respect to their genetic identity and desiccation tolerance (all work at University of Oregon).

B) The work with *Cyanidium* and related eukaryotic algae involved the collection of live specimens from numerous thermo-acidic habitats over much of Yellowstone National Park. Many strains were isolated, and the ribosomal 18S DNA is being sequenced for many of these. Preliminary studies have shown that heterotrophic growth of most of the strains is negligible; some are unable to grow with nitrate as the nitrogen source; and growth on soil and water taken from various native sources containing heavy metals was slow to nil, but differed among strains (work done at Montana State University and University of Oregon). The tolerance of *Cyanidium* strains to aluminum is presently being tested.

Project title: Physiology and Geochemical Tracing of FeS/H2S Microorganisms in Subsurface Hydrothermal Environments

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Objective: Analyze diversity of prokaryotes associated with acidic sulfurous hot springs.

Findings: I did not travel to or sample in YNP during 2002 and am continuing my characterization of microbial strains isolated during previous years. I do not wish to renew my research permit for 2003.

Project title: Transition Between Lithoautotrophy and Chemoheterotrophy in *Sulfolobus* Species

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Objective: Understand the relationship between lithoautotrophy and chemoheterotrophy of acidophilic hyperthermophilic archaea in situ.

Findings: None, not active this year.

Project title: Functional and Molecular Ecology of Hot Spring Microbial Mats

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Objective: The year has primarily been used to continue data analysis and to submit several publications. One publication on the diversity of *Chloroflexus*-like bacteria in hot spring mats was published, while a manuscript on cyanobacterial ecotypes in hot springs is currently in review.

Findings: n/a

Project title: Bacterial Diversity of Thermophilic Anoxygenic Phototrophs

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Objective: To obtain living stock cultures of photosynthetic bacteria capable of growing at high temperatures. These organisms will contribute towards the ultimate goal of defining the upper temperature limit for photosynthesis on Earth, and determining the effects of heat on photosynthetic pigment-protein complexes.

Findings: Sampling occurred in July, September, and November 2002. Enrichment cultures for phototrophic purple and green bacteria were positive at 40–65°C from samples collected in the Lower Geyser Basin, Nymph Creek area, and Mammoth Upper Terraces. From Octopus Spring (White Creek Drainage, Lower Geyser Basin), new strains of the green phototroph *Chloroflexus* were obtained. In addition, a new filamentous bacterium lacking the bacteriochlorophyll c found in *Chloroflexus* was enriched from this source, and attempts are ongoing to get this organism into pure culture. From the Mammoth Upper Terraces, new strains of the purple bacterium *Thermochromatium tepidum* have been isolated. Also from Mammoth are the first successful enrichments for *Chloroflexus*-like phototrophs. Such were described some 15 years ago but the original cultures were lost. With all isolates, 16S rRNA sequencing is being used to track the phylogeny of these organisms relative to cultured and uncultured species from the same habitat. All pure cultures obtained in which publication is made are deposited in either the American Type Culture Collection (ATCC, Rockville, MD) or the Deutsche Sammlung von Mikroorganismen und Zellkulturen (DSMZ, Braunschweig, Germany), or both.

Project title: Enhanced Practical Mitigation of Carbon Dioxide

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Additional investigators: Barbara W. Cooksey, Igor Broun

Objective: Our aim for 2002 was to increase the diversity of our collection of cyanobacteria from Yellowstone National Park. The cyanobacteria are being studied from a physiological point of view in order to select the most suitable for use in a carbon-dioxide mitigation reactor. We carried out three samplings during summer and fall of 2002. In particular, we took three samples from Narrow Gauge pool, one sample from the Angel Terrace pool, and three samples in West Thumb Geyser Basin.

Findings: Macroscopic analysis of samples collected in Narrow Gauge pool showed that they are stromatolites which were shaped like bunches of grapes attached to the calcite surface by a short foot. The most interesting peculiarity of these stromatolites is that these structures are filled with calcite crystals. Microscopical analysis of a sample isolated from conical fountain in West Thumb Geyser Basin showed that this is composed with filamentous cyanobacteria, probably *Phormidium*. Interestingly, living filaments were also found at 5 cm depth. Microscopical analysis of samples isolated in Angel Terrace pool suggested that this mat is composed of several species of filamentous cyanobacteria and unialgal

Synechococcus. All samples were transferred to standard laboratory media, i.e., BG-11, D and DH to obtain growing cultures. It was found that all field samples were able to grow well in standard laboratory media within a temperature range 45–55°C, but with different requirements for light intensity. At the moment we are attempting to obtain monospecific isolates from these field samples.

Project title: Isolation, Identification, and Characterization of Microorganisms Living in Extreme Environments

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Objective: To educate undergraduate students about the geology, ecology and most particularly the microbial diversity in Yellowstone thermal areas. The students learn about environmental sampling and on-site analysis of water samples, looking at salt levels, heavy metal concentrations, pH levels and temperature variations. These analyses are designed to assist us in trying to develop media for propagation of extremophilic microbes.

Findings: This past year, I had four students arrive in the park for a one-week sampling and backcountry trek into park thermal areas. Word of mouth has made this a popular course with the students at my college and I have another group of interested students for this upcoming summer. I have necessarily limited my course size to five students to limit any potential impact on the environment and because logistically this is a manageable number of students.

Project title: Diversity and Biogeochemistry of Thermophilic Anaerobic Microorganisms

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Additional investigators: Jennifer E. Kyle, Chris Romanek, Carry Aye Jones,
Paul Schroeder, Doug Crowe

Objective: Elucidation of the biogeology, ecology, phylogeny, phsyiology, and diversity of thermophilic microorganisms, presently with aspecial focus on alkalithermophiles as a novel group of extremophiles. We are interested in the interaction of the microbial activity with geochemical processes in geothermal features and how far they influence each other.

Findings: Due to missing funds, especially for the travel of our undergraduate trainees, most of the microbiology research was put on hold. The biogeochemical analysis of the sinter material removed during 2001, is presently further analyzed. This work will be presented as a poster at the International Symposium THERMOPHILES '03 in Exeter, England, and a publication will be prepared during 2003. Furthermore a publication will be prepared on an iron reducing bacterium isolated in the past from a sample collected at the Calcite Spring. We hope to obtain more funds during 2003 to continue the work.

Project title: A Microbial Inventory of the Greater Yellowstone Ecosystem Thermal Features

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Additional investigators: Anna Louise Reysenbach, YCR Spatial Analysis Center Staff, Ann Rodman, Kendra Maas

Objective: The overall objective of the project is to survey the microbial phylogenetic (16S rRNA of Bacteria and Archaea) diversity and describe the geochemical characteristics of 100 thermal sites in the GYE. The survey will be conducted in conjunction with a spatial inventory currently being done by the Yellowstone Center for Resources. The project will result in a microbial inventory housed in a web-accessible relational database, which would be one of the first of its kind to link microbial phylogenetic sequence data and geochemical measurements to spatial data (GIS). In addition to 16S rRNA genes, the project will screen sites for selected physiological genes, including sequences indicative of sulfate reduction, methane production, ammonium oxidation, and nitrogen fixation, which will be useful in further defining geochemical and phylogenetic co-relationships. This project will provide a baseline of microbial diversity in the GYE that could be used for monitoring diversity and managing microbial resources.

Findings: Microbial mat and filaments, sediment, soil, water, or rock was collected from 216 thermal sites. The samples were collected from Norris Geyser Basin, Shoshone Geyser Basin, Upper Geyser Basin, Lower Geyser Basin, Lone Star Geyser Basin, Mud Volcano, and Highland High School and Glen Africa Basin near Mary Mountain. The total sample volume collected was approximately 1.2 liters. We have begun analysis of the microbial communities represented in the samples using DGGE or cloning and DNA sequencing.

Project title: Genetic Analysis of *Brucella* from Bison and the Generation of a PCR-Based Diagnostic System for Epidemiological and Ecological Studies

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Objective: (1) Compile and analyze genetic data, and (2) prepare and submit a manuscript to a peer-reviewed journal.

Findings: A manuscript describing this work is curently in review.

Project title: Spectral Analysis of Hyperthermophile Organisms and Sinter Deposits

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Additional investigators: Jeffrey Johnson, Arthur Lane, Pamela Conrad, Michael Storrie-Lombardi

Objective: The objectives of the study are to characterize the spectral reflectance properties of extremophile mats associated with springs and geysers in Yellowstone National Park, sinter deposited in and associated with the thermal features and the extent to which the spectral signature is retained in inactive sinter. Spectral reflectance measurements are obtained in situ from 350–2,500 nm. This spectral range includes characteristic absorptions associated with chlorophylls, bacteriochlorophylls, and carotenoids, in addition to mineral absorptions. Target sites have both high temperature and high acidity organisms. Sites investigated include Octopus Spring, Mushroom Spring, Norris Basin, Chocolate Pots, Lemonade Creek, Nymph Creek, and Mammoth Terrace. In active sinter from a variety of sites have been examined.

Findings: At each target location spectral data are collected of the mat from the source downstream until the mat disappears, or along a creek bed (e.g., Lemonade Creek), and of the surrounding sinter deposits (both in place and disturbed). Reflectance data are typically obtained through the flowing water (which is typically a cm or so deep) and occasionally of pieces of the mat which have been removed from the water (after the measurement the mat is replaced). The data show that each of the major communities within a spring have characteristic spectral absorptions resulting from the specific types and amounts of chlorophylls, bacteriochlorophylls, and carotenoids present. Variation among spectra for a single community is small compared with the differences observed between communities. The spectra of similar communities (e.g., *Cyanidium* spp.) from different locations (e.g, Lemonade, Norris, and Nymph) are very similar and very different from other communities. Examination of the sinter shows that when a mat community is present, absorptions due to organic compounds are observed in the sinter. Many exposures of inactive sinter have endolithic communities living just below the surface.

Project title: Production and Consumption of Trace Gases by YNP Microbial Communities

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Additional investigators: Scott Robert Miller, Mary Hogan, Victoria Orphan, Tori Hoehler, Steven Carpenter, Ulrich Nuebel

Objective: Determine the production and consumption of trace gases in a number of microbial mat communities

Findings: Unfortunately, we were unable to get to YNP this year, and so have no findings to report.

Project title: Ecology of Hot Spring Microbial Communities

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Objective: (1) We continued two approaches to testing the hypothesis that cyanobacterial diversity in mats of alkaline siliceous hot spring results from adaptive evolutionary radiation. a) We submitted a manuscript on vertical distribution of oxygenic photosynthesis, light, oxygen and genetic diversity of cyanobacteria at 68°C in the Mushroom Spring mat (now in press in *Applied and Environmental Microbiology*). b) We continued efforts to cultivate genetically relevant *Synechococcus* isolates from such mats for characterization of their adaptations to temperature and light.

(2) We completed a study of local to global geographic variation of hot spring *Synechococcus* (and other cyanobacteria), in an effort to understand whether geographic isolation could be another important driver of genetic diversification of microorganisms. A Ph.D. thesis describing the results was completed (Papke 2002), and we submitted a paper on this work for publication (now in press in

Environmental Microbiology).

(3) We published a study of the diversity and distribution of green nonsulfur-like bacteria (GNSLB) (Nuebel et al. 2002).

(4) We continued research on the diversity of green sulfur-like bacteria in Yellowstone springs done in collaboration with Dr. Donna Bedard (RPI), who will report the results separately.

(5) We continued organic geochemistry studies of hot spring microbial mats in order to: a) cultivate and characterize major phototrophic microorganisms that are genetically relevant to the mats. For instance, we published a paper that describes the lipids of a Japanese GNSLB isolate, *Roseiflexus castenholzii*, which is the closest phylogenetic relative of the GNSLB organisms that dominate in Yellowstone mats (van der Meer et al. 2002). We also initiated work with our collaborator, Dr. Michael Madigan,to try to cultivate the Yellowstone type-C organisms. b) Understand how stable isotope signatures of organic compounds produced by mat phototrophs arise through different biochemical processes. In particular, we are trying to understand how autotrophic processes and sugar biosynthesis affect the stable carbon isotope signatures of organic compounds produced by cyanobacteria and GNSLB.

Findings: (1) a. We demonstrated that at 68°C, subsurface, pigment-rich *Synechococcus* populations are genetically indistinguishable from *Synechococcus* nearer the mat surface by variation at the 16S rRNA locus, though the two populations are genetically distinct at the adjacent internal transcribed spacer (ITS) locus. These results cast doubt that 16S rRNA methods (and possibly also ITS methods) can detect all ecologically distinct populations of a microbial community. A manuscript reporting results at four temperature-defined sites will include another interesting observation that, at 65°C, phenotypically distinct surface and subsurface populations cannot be distinguished at either the 16S rRNA or the ITS loci. These represent either a single population that acclimates differently along a light gradient, or >1 population that are even more closely related. b) We have cultivated numerous *Synechococcus* isolates and have characterized them genetically. To date we have succeeded in recovering representatives of 16S rRNA genotypes B, B' and A, which are typical of low-temperature in situ populations. In some cases isolates have ITS sequences identical to those found in situ. Purification is in progress in advance of adaptation experiments.

(2) Our results challenge the paradigm that "everything is everywhere and nature selects". *Synechococcus* (and other native cyanobacteria) that are genetically distinct at the 16S rRNA locus were found in springs in different countries. North American springs contained the greatest diversity of genotypes, including the predominant genotype that is limited in distribution to North America. Japanese springs were dominated by a second genotype that is also rarely observed in Yellowstone. New Zealand springs were dominated by filamentous cyanobacteria; a third *Synechococcus* genotype (that is the most widespread among countries) is subdominant, but rare outside of New Zealand. Hence, different *Synechococcus* genotypes showed different patterns of distribution that could reflect different propensity for dispersal. Populations that are genetically distinct at the ITS locus were found among springs within countries (e.g., Japan) and regions (e.g., Yellowstone). Patterns of genotype distribution could not be correlated with patterns of chemical character, suggesting that geographic isolation is part of the explanation for the results.

(3) GNSLB showed high levels of 16S rRNA-based diversity within the Mushroom Spring mat. Both *Chloroflexus* and type-C sequences were detected in cloning studies. FISH probing demonstrated the filamentous nature and predominance of type-C GNSLB at 60°C and their co-dominance with *Chloroflexus* spp. at 68°C. Combined FISH microautoradiography was used to demonstrate that

Chloroflexus and type-C filaments are capable of photoheterotrophic metabolism.

(4) See Bedard report.

(5) a) *Roseiflexus castenholzii* was found to contain C37–40 wax esters and alkane-1-ol-2-alkanoate lipids glycosidically bonded to a hexose that resemble lipids found in mats of alkaline siliceous springs of Yellowstone. Through collaboration with Dr. Madigan, we have enriched GNSLB that appear to be much more closely related to the type-C GNSLB of mats in Yellowstone springs, as well as *Chloroflexus* strains that may be more relevant to specific mats. Following purification and physiological studies, these isolates will be used in studies of lipid and sugar biomarkers, their production relative to environmental variables, and isotopic fractionation. b) Mushroom Spring samples collected at regular intervals through a diel cycle were analyzed for polyglucose content. Polyglucose concentrations rose during the day and declined during the night. This trend was also observed in *Synechococcus* cells, which were separated from GNSLB filaments using Percol gradients. These samples will soon be used to study the 13C content of sugars and lipid biomarkers.

Project title: Population and Genetic Diversity of Microorganisms Associated with Hydrocarbon Deposits in Thermal Areas

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Additional investigator: William P. Inskeep

Objective: (1) Compare soil microbial diversity among sites containing naturally occurring petroleum deposits; (2) examine functional gene diversity and evolutionary relatedness to characterized genes encoding hydrocarbon-degrading enzymes; (3) characterize the abundance and types of hydrocarbons present; (4) enrich for hydrocarbon-degrading isolates and compare them to currently described organisms.

Findings: Soil samples were collected from the Calcite Springs area in August 2002. Chemical analysis (GC-MS) of the samples revealed a range of polynuclear aromatic hydrocarbon concentrations in the soil samples. Additional samples are currently being stored at Montana State University for upcoming molecular analysis.

A second trip to the Rainbow Springs area is scheduled for summer 2003. Soil samples obtained from this trip will also be subject to chemical and microbiological analysis.

Project title: Survey of Yellowstone Hot Springs for Green Sulfur Bacteria

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Additional investigators: David M. Ward, Mary Bateson, Greta VanSlyke Jerzak, Uli Nuebel

Objective: (1) To survey selected hot springs in Yellowstone National Park for the presence of green sulfur bacteria (GSB); (2) to study the diversity of GSB inhabiting Yellowstone hot springs; (3) to study the microbial community structure of Yellowstone hot springs inhabited by GSB; (4) to isolate and characterize GSB inhabiting Yellowstone hot springs; (5) to further characterize and isolate organisms whose 16S ribosomal gene sequences indicate that they may be deeply branching relatives of green sulfur bacteria from selected Yellowstone hot springs.

Findings: We continued our study using targeted PCR and enrichment techniques to survey hot springs in Yellowstone National Park for GSB. We have found GSB in several small sulfidic hot springs (34.3–67.4°C, pH 5.4 to 6.9, 1 to 28 mM sulfide) in the Gibbon Hills area, the Mud Volcano, and Mammoth Hot Springs region. There were several small visible mats of GSB in both the Mud Volcano and Gibbon Hills regions. GSB enrichments from these mats grew photoautotrophically with incandescent light at 34– 44°C on minimal medium using sulfide and thiosulfate as the electron donor. Cells enriched from multiple sites at these locations are small nonmotile rods (0.24–0.28 mm, 0.5–1 mm) containing chlorosomes, bacteriochlorophyll c and chlorobactene. The GSB mats in the Gibbon Hills region also contain cyanobacteria and probably purple sulfur bacteria. In contrast, GSB appear to be the sole phototrophs in several hot spring mats that we sampled in the Mud Volcano region.

Targeted PCR also amplified GSB sequences from phototrophic mats at Angel Terrace and Narrow Gauge Springs in the Mammoth Hot Springs region. However, these latter mats appeared to be composed primarily of Chloroflexacae and we were unable to obtain GSB enrichments from them.

Partial sequences of PCR-amplified GSB16S rRNA genes from DNA extracted from the hot springs in all three regions of the park and from GSB enrichments derived from the corresponding sites indicate that the sequences were nearly identical, regardless of source or temperature. These sequences are most closely related to strains of *Chlorobaculum limnaeum* and *Chlorobaculum tepidum*.

Project title: Isolation and Characterization of Thermophilic Microorganisms

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Objective: (1) To obtain and identify additional culturable thermophilic and other microorganisms that are found in natural hot spring in the Yellowstone Ecosystem; (2) to investigate the properties of selected enzyme found to be produced both in pure culture and natural microbial communities.

Findings: Prior to starting the Yellowstone National Park 2002 summer fieldwork, I asked a student, Kris Kashyap, to re-examine some previously collected Yellowstone hot spring samples (stored in 25% (w/v) glycerol storage medium at -70'°C) for extremely slowly growing microorganism that might have been overlooked in previous isolation studies. Using a wider range of temperatures and pH?6s, Kris Kashyop was able to isolate an apparently previously un-described, slowly growing, red pigmented, gram negative, non spore-forming bacterium with an optimum growth temperature of 30–45° C and an optimum growth pH of 8–9.5 from a thermal pool sample that had been collected from the West Thumb Geyser Basin during the summer of 2000. The specific sample had been collected at that time at the request of the Yellowstone Center for Resources. (The reason for this request had been the observation by the seasonal naturalist at West Thumb Geyser Basin that this specific hot spring pool had developed a oil like sheen following a local earthquake swarm.) Preliminary examination of that West Thumb Geyser Basin samples at that time had shown the growth of *Thermus*, *Meiothermus* and spore forming *Bacillus* isolates but had not shown anything especially unusual.

During the summer field work of 2002, we obtained additional similar, red pigmented isolates from samples collected from a small unnamed hot spring pool located just upstream from the Five Sisters Hot Spring in White Creek and from the Twin Butte Overlook Hot Spring (just north and up the hill from Octopus Spring).

16S rRNA analysis of the three isolates showed that all three isolates were apparently identical and the 16S rRNA sequence was most closely related to a red pigmented bacterium Akaite c 9 (AJ431335) previously isolated by Stougaard (et al.) from a cold alkaline spring in Greenland (*Environmental Microbiology* 2002, 4:487-493), except that the Yellowstone isolates have a higher optimum growth temperature. The Yellowstone isolate fall within the general Cytophaga, Flavobacterium, Bacteroides (CFB) group and are slightly more distantly related to an unidentified isolate from a soda lake in Inner Mongolia (AF275712), an uncultured bacterium associated with Caribbean marine sponges (AF489285), a *Cyclobacterium* sp. V4.MS.32 from the Mediterranean Sea and an number of uncultured DFB bacteria from Angel Terrace in Yellowstone with the uncultured bacterium AF445684 16S rRNA sequence having the closest match of those CFB 16S rRNA sequences.

Conversations with Dr. Stougarrd at the International Extremophiles Meeting in fall 2002 confirmed that neither our Yellowstone nor his Greenland isolates show the circular morphology described for *Cyclobacterium*. However an interim working title proposal is to identify this present Yellowstone isolate as *Cyclobacterium ruber* even though it is probable that the genus name is likely to be changed pending additional isolates etc. The 16S rRNA sequence of the Yellowstone isolate has been deposited in GenBank as *Cyclobacterium ruber*.

In addition to this Yellowstone isolate, additional moderate temperature isolates have been obtained from lower temperature hot springs in the Huckleberry/Polecat region in the Roosevelt Parkway south of Yellowstone National Park and from Colorado and India hot springs. Included in these isolates are pigmented bacteria are isolates that are related to *Deinococcus proteolyticus* (Y11331), *Agrobacterium albertimagni* (AF316615), *Agrobacterium sanguineum* (AB062105), *Rathayibacter rathayi* (U96186), *Roseococcus thiosulatophilus* (X72908), *Craurocossu roseus* (D85828) and *Exiguobacterium acetyicum*. It may be likely that hot springs containing high carbon dioxide and carbonate especially favor the growth of CFB type bacteria like the present *Cyclobacterium ruber* isolate.

Project title: The Microbiogeochemistry of Sublacustrine Hydrothermal Vents in Yellowstone Lake, WY

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Objective: (1) Yellowstone vent throat habitats are capable of sustaining thermophilic microbial communities in situ, resulting in gradients of thermophilic to extreme thermophilic bacteria with different nutritional characteristics within vent conduits, from deep in the conduit to the mouth of the vent. (2) Vents in different basins will support different types of extremophile communities because each biogeochemical domain provides vent water sources of differing composition with respect to energy sources (e.g., reduced iron, manganese and sulfur; hydrogen; methane). (3) Significant microbial activity occurs in vent field sediments, resulting from seepage of vent fluids and fracture zones.

Mineral inputs to Yellowstone Lake come from a variety of sources, including hydrothermal vents, ground water, rainwater, flux from sediments and direct runoff. One third of Yellowstone Lake is directly influenced by hydrothermal activity (hot water vents and fumaroles). Geothermally heated water percolating through the chamber is highly enriched in carbonate, silicate, chloride, and methane, with some locations additionally rich in iron and sulfide.

Microorganisms that live in high temperature ecosystems are tightly coupled to their environment. A detailed understanding of the geochemistry of hydrothermal environments can be an important component in deciphering critical characteristics for the presence of microbial life under these changing conditions.

More than 25 chemosynthesis incubations included more than 20 vent samples and an array of associated water column samples. Due to weather and scheduling constraints, the West Thumb and Mary Bay areas of the lake were intensely sampled while Stevenson Island and outlying areas near Mary Bay were postponed until 2002. This permitted us to apply more detailed analyses of chemosynthesis in the two regions than had been possible in previous years. Especially improved in 2001 (but not yet optimized) was examination of high temperature chemosynthesis (50–70°C) in parallel with in situ temperature incubations.

Vent waters in West Thumb typically contained sub-micromolar concentrations of Fe while those in Mary Bay and off Stevenson Island contain up to 10M. The water column concentrations of dissolved Fe range from 250 to 450 nM in Mary Bay, but were below detection (180 nM) in the waters of South East Arm, West Thumb, and off Stevenson Island.

Pore water and vent water chemistry provide evidence for lake water dilution of vents below the sediment-water interface. Significant fracturing of source water conduits was indicated by extreme differences in pore water profiles from cores less than 5 m apart in geothermally vigorous West Thumb. Some samples approached theoretical reservoir composition for conservative geochemical tracers.

Porewater results from the geothermally active areas of Mary Bay and West Thumb show Cl- enrichments reaching several mmolar and, in the case of Mary Bay, extrapolate to the geothermal end member (~ 20 mM) at a depth of only 2–3 m. These steep concentration gradients support diffusive Cl- fluxes across the sediment-water interface 3 orders of magnitude higher than those in non-venting depositional areas.

Findings: Based on several parameters, we have grouped the different active areas of the lake into domains, namely: North Basin (includes Steamboat Point, Mary Bay), Stevenson Island, and West Thumb. Some of the measurements include: silicate, chloride, total CO^2, methane, hydrogen sulfide, and dark CO^2 fixation.

It is clear that the enrichment of certain elements is not widespread throughout the lake and is not uniform either. These severely impact the microbiology and physiological response of the microbial populations on the different areas. Another relevant component that adds another dimension to the domains picture, and that is temperature. Differences in temperature in the diverse vents vary within the different domains as well as within the domains themselves.

Chloride is an element that is enriched in hydrothermal areas, as seen in 2002 as well as in previous years, West Thumb has been an area where chloride is more enriched that in other areas of the lake.

Methane has been consistently absent from the West Thumb area and it is found in higher concentrations in Mary Bay and Stevenson Island vents. This year there were vents with a low concentration.

Hydrogen sulfide was present in high concentrations in the north area of the lake, as well as in Stevenson Island, which showed the highest concentrations.

Chemosynthesis results show the trends we have been observing in the past years, where Mary Bay and Stevenson Island have areas that show a significant chemosynthetic response.

Metals such as manganese and iron are an important component of the solid phase material on the bottom of the lake in an oxidized form. Hydrothermal vents in Mary Bay have high concentrations of reduced manganese an iron. The solid phase samples in Mary Bay show the signs of oxidation of manganese and iron, some of the solids have a patina of minerals, whereas other areas have thicker layers of the oxides.

Reduced iron is found in very low concentrations in ventwaters in the West Thumb area. The solid material shows an abundant covering of manganese and iron oxides present in the area.

The distribution and diversity of methane-oxidizing (methanotrophic) bacteria and methane in both the water column and hydrothermal vents of Mary Bay. Estimations of the number of methanotrophs are being made with a Most Probable Number-Polymerase Chain Reaction (MPN-PCR) technique using specific primers for the gene of an enzyme that is found in all known methanotrophs, particulate methane-monooxygenase. Estimations of methanotroph numbers have been completed from three water column profiles (1997, 1999, and 2001). Numbers in the water column were estimated to be between 1.0 x 100 to 5.0 x 104 cells/ml. In the water column of Mary Bay, the highest estimations of cells have been observed with the highest concentrations of methane. However, this does not hold true for hydrothermal vents. In vent water samples methanotroph numbers ranged between 2.5 x 102 and 4.75 x 104 cells/ml.

Last year we started to examine Archaeal diversity in the water column. In samples collected during summer stratification, using primers specific for the 16S renal gene in Archaea and the PCR, we were able to amplify genes from samples collected below the thermocline but not in the epilimnion. The data suggest that the thermocline is somewhat of a barrier to mixing of the Archaea from the vents and the hypolimnion into the epilimnion. We are currently examining the water column samples taken this past

year and in previous years to confirm our observations. The Archaeal DNA from a couple of the samples has been cloned and the clones examined using Amplified rDNA Restriction Analysis (ARDRA). Several of the different patterns are ready for sequencing and phylogenetic analysis.

Project title: Characterizing DNA Methylase and Restriction Enzyme Genes in Environmental DNA

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Additional investigator: Richard D. Morgan

Objective: Restriction enzymes are one of the key reagents used in molecular biology. They recognize specific sequences within DNA and cleave at, or close to, this recognition sequence. More than 3,300 of these enzymes have been characterized worldwide, and more than 500 are available commercially (Roberts and Macelis 2002). At present, we know of restriction enzymes that are able to recognize more than 240 different specific sequences. However, there continues to be an interest in finding both enzymes that recognize new specific DNA sequences (enzymes with new specificities) and enzymes with novel properties that may make them especially suitable for certain applications, such as increased thermal tolerance.

We are interested in several outcomes from this research. First and foremost, we hope to isolate and characterize some new restriction endonucleases with novel properties. These would include enzymes that recognize completely new DNA sequences or enzymes with new properties, such as far more stable isoschizomers (enzymes recognizing the same DNA sequence) of known enzymes, or enzymes that recognize the same sequence as a previously known enzyme but that cleave the DNA in a different position (such enzymes are called neoschizomers). Secondly, we hope to isolate and characterize DNA methylase genes, which comprise the second essential part of the restriction-modification systems we wish to study. We also aim to identify the organisms present in the samples studied by amplifying and sequencing the 16s rRNA genes present in the samples. To access the restriction-modification systems we isolate DNA from a thermophilic prokaryote mat or filament sample, then prepare a DNA library from the isolated DNA. We then employ one of several methods to identify clones that carry restriction-modification genes. The enzymes thus identified are characterized biochemically to determine their properties. The DNA sequence of selected clones is determined so that the enzymes can be compared to other restriction and modification enzymes.

Findings: No visits to Yellowstone were made in 2002. During 2002 work was performed on a sample (sample WC5.5) collected in the White Creek area in 2001. This WC5.5 sample consisted of a mixture of pink, orange, tan and green filaments growing in the effluent channel of a hot spring at approximately 70°C, pH8.5. DNA was purified from a 1.5ml sample of these prokaryotic filaments using a chemical lysis procedure (lysozyme, proteinase-K and SDS, followed by 3 freeze-thaw cycles). This procedure yielded approximately 20 micrograms of DNA, most of which was greater than 10 kb in size. A clonal library was made from this DNA sample. The DNA was digested with 14 different restriction enzymes that leave blunt ends. An oligonucleotide having one blunt end and one asymmetric end was then ligated to the DNA. The DNA was size selected on an agarose gel for fragments of 2 kb to 10 kb. These fragments were ligated to a pUC19-derived vector having compatible asymmetric ends. The library generated contained approximately 1,000,000 individuals.

The methylase selection method was employed to see if several commonly occurring restriction systems might be represented in this library. The endonucleases HaeIII (recognizing 5'-GGCC-3'), MseI (recognizing 5'-TTAA-3'), and TaqI (recognizing 5'-TCGA-3') were used. DNAs conferring resistance to each of these endonucleases were identified. This result confirms that restriction modification systems are present in the bacteria and/or archaea inhabiting this thermal environment of YNP. The enzymes identified in this initial screen will be further characterized and compared to previously known examples. We plan to form new DNA libraries and to search them for novel restriction endonucleases and methyltransferases.

Project title: Geochemical Constraints on the Ecology of the Deep Lineages Within the Bacteria and Archaea

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Objective: (1) To determine the microbial diversity and geochemistry associated with high temperature thermal springs in YNP; and (2) To study the ecology and metabolic diversity of microbial communities inhabiting high temperature thermal springs in YNP

Findings: We initiated our collaboration with the park to analyze the microbial diversity associated with the geothermal features. These data will be added to a database that will form a survey of the current status of microbial diversity in Yellowstone geothermal features. Initial areas studied were: Shoshone Geyser Basin, Amphitheater Springs, Smoke Jumper Hot Springs, and Sylvan Springs. Some organisms identified from these springs include Aquificales and cyanobacteria; confirming the importance of these lineages within geothermal features in Yellowstone.

Project title: Analysis of Metal Resistance in Yellowstone Bacteria

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Additional investigators: Deborah T. Newby, Mark E. Delwiche, David Barrie Johnson, Heather G. Silverman

Objective: Isolation and characterization of thermophilic, thermoacidophilic, and other bacteria and archaea from locations throughout Yellowstone to identify these microorganisms on the basis of 16S rRNA gene sequences and determine mechanisms of metal resistance/tolerance at the genetic level in these microbes. Isolates may also be used in other INEEL research (V. Thompson, W. Apel, co-PIs) screening for novel enzymes, and collaborative work with Montana State University (M. Young, D. Mogkt, K. Steadman, co-PIs) supported by NSF Microbial Observatories program examining thermophilic viruses in *Sulfolobus* and other Crenarchaeota.

Findings: Three enrichment cultures have been maintained at pH 2 and 70°C growing on elemental sulfur. These cultures are being compared to other crenarchaeota, including *Sulfolobus acidocaldarius*, *S. metallicus*, *S. solfataricus*, *Metallosphaera sedula*, and *Acidianus brierleyi*.

A real-time PCR assay for thermoacidophilic crenarchaeota was developed and is being used to identify and quantify these archaea in geographically distinct environments in Yellowstone.

Project title: Biomolecular Diversity in Yellowstone National Park

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Additional investigators: Jay M. Short, Leif Christoffersen

Objective: Diversa is interested in exploring the microbial diversity at Yellowstone. We are still focusing on microorganisms that reside in high and low pH environments, and we are also expanding our research activities to include discovery of microorganisms that are associated and prefer habitats that are high in oils (of all types).

Findings: Diversa did not engage in any research activities in Yellowstone in 2002. We are hoping to engage in research activities later this year (2003). We still do have specimens from previous field sampling trips from Yellowstone, however, we are not doing any work on them until the EIS is complete.

MONITORING NATURAL RESOURCES

Project title: A Remote Sensing and GIS-Based Model of Habitat as a Predictor of Biodiversity

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Additional investigator: Dr. Kelly Kindscher

Objective: (1) To continue our long-term inventory and monitoring of biodiversity of songbirds and butterflies in montane meadows of the Greater Yellowstone Ecosystem; (2) to conduct some pilot research that will allow us to sort out the relative effects of habitat type, vegetation structure, and landscape context on nesting success of the willow-dependent songbirds. This work is focused in the Grand Teton National Park region but is highly relevant to Yellowstone Park as well.

Findings: (1) Long-term bird and butterfly species distribution patterns are now being analyzed relative to six meadow types in the Greater Yellowstone Ecosystem (including sites in Grand Teton National Park and Yellowstone National Park, and some of the surrounding National Forest lands). We have recently aquired some funds from the Iowa Space Consortium to move this research into the realm of global climate change by analyzing interannual variability in remotely sensed classifications of the study sites in conjunction with interannual changes in species distribution patterns. (2) Our willow-dependent songbird study was focused on yellow warblers. During our pilot study in 2002, we established standards in nest searching, monitoring, and recording using 29 nests. Nest locations were determined with a GPS and recorded in UTM coordinates. We monitored nests every 3–4 days until each nest's fate was realized and the resultant data were used to calculate daily and periodic survival probability for each nest. In order to minimize observer effects, we avoided creating "dead end" trails that lead to nests and used a mirror pole for identifying nest contents at a distance.

We used the nest coordinates to begin a GIS database of nest locations within each willow patch. Using ArcView GIS 3.x, ArcView Spatial Analyst, and ArcView Patch Analyst, we will calculate the following patch- and landscape-level metrics: a) distance-to-edge for each nest, b) habitat types adjacent to each edge, c) individual patch area and mean and total patch area for the entire landscape, d) individual and mean perimeter-to-area ratio, and e) core area per patch and mean and total core area for the landscape. Multivariate statistical analyses will be used to assess the effects of habitat type, vegetation structure, and landscape context on songbird abundance and species richness.

Project title: Trace Element Content of Cervid Antlers

Principal investigator: Dr. Jack Kovach
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Objective: I am studying the strontium isotopic composition and the content of strontium and other trace elements in elk and deer antlers from selected national parks in the western U.S., including Yellowstone. The study will add to the general body of knowledge about the cycling of trace elements through the environment and increase our understanding of the biogeochemistry of strontium. The study will provide baseline data from which future changes may be gauged. (A copy of the research proposal which I submitted to the Green Educational Foundation [which has provided $l2,017.00 for this study] is on file in the Research Office, Yellowstone Center for Resources, Mammoth Hot Springs, Yellowstone National Park.

Findings: No significant findings to date inasmuch as no analytical data are yet available. Evidence of antler-chewing/osteophagia by Yellowstone elk has been obtained from several areas of Yellowstone's northern range, and such activities are likely related to the major and/or trace element content of the antlers/bones and the nutritional status of the elk. Much of my field work in 2002 was directed toward determining the geographic distribution and frequency of occurrence of antler-chewing/osteophagic behavior through observations of skeletal remains of dead animals and cast (shed) antlers of elk and mule deer, mostly on Yellowstone's northern range.

Project title: Monitoring Forest Response to Past and Future Global Change in Greater Yellowstone

Principal investigator: Dr. Andrew Hansen
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Additional investigators: Nick Lyman, Warren Cohen, Lisa Graumlich, Bard Zajac, Scott Powell, Michael Lefsky

Objective: The Greater Yellowstone Ecosystem (GYE) has experienced rapid change in vegetation over the last century, driven by interactions between land use and climate variability. Conifer forests in parts of Yellowstone National Park have been expanding since at least 1890, and deciduous forests, grasslands, and shrublands, in contrast, have declined during this period. The spatial pattern of this vegetation change might not be random across the landscape; rather it appears to be predictable based on biophysical factors. Understanding the directions, rates, and locations of these past changes sets a context for designing a monitoring scheme to detect future change. Changes in vegetation are likely to have important consequences for carbon sequestration and biodiversity. The influence of forest expansion and fire exclusion on carbon uptake in the Rockies is a major source of uncertainty in estimates of the U.S. contribution to global carbon emissions. Many native species are likely experiencing reductions in population viability due to changes in habitat.

Specific objectives of this study are to: (1) Quantify change in forest cover, density, and composition across the GYE during 1971–1999 using a combination of satellite imagery and aerial photographs. (2) Assess the consequences of this change for carbon sequestration by field measurements of tree, snag, and shrub composition and structure, herbaceous biomass, and coarse woody debris volume and density. These data will be used to derive allometric equations for aboveground biomass and carbon stores for each of our vegetation classes quantified in objective 1. (3) Assess the consequences of this change for biodiversity (specifically birds and shrubs) by modeling species abundance as a function of vegetation structure and composition as well as biophysical factors. Models will be extrapolated across the landscape according to our vegetation classification derived from objective 1.

Findings: We have completed analysis of the rates and distribution of change in forest cover, density, and composition across the GYE from an assessment of greater than 2,000 air photo samples from between 1971 and 1999. Our results indicate that 4.9% of samples across elevation, aspect, and cover type gradients exhibited conifer expansion (e.g., went from non-conifer to conifer) while 17.5% of samples exhibited conifer densification (e.g., increased in conifer density). Rates of change over the 28-year time varied between 0.36% per year and 3.57% per year depending upon biophysical location. Below 2,000 m, greater than 15% of the samples exhibited conifer expansion compared to less than 5% of samples above 3,000 m. Rates of conifer expansion were highest at lower elevation, with a mean rate of increase of 0.65% per year at 1,700m compared to 0.43% per year at 3,000 m.

Progress continues to date on accurately modeling hierarchical vegetation dynamics using satellite imagery. Air photo reference samples were used in two distinct manners for quantification of vegetation dynamics. Firstly, Landsat spectral data from multiple time periods were classified using a classification tree approach to produce a discrete hierarchical vegetation classification for cover type and seral stage. Change between 1971 and 1999 was determined by spectral thresholding and only "change" pixels were reclassified in the earlier time period to minimize classification error. Secondly, percent conifer cover was modeled as a function of Landsat spectral data from 1985 and 1999. For a portion of the study area for 1999, percent conifer cover was modeled with 72% accuracy. Percent conifer cover change between 1985 and 1999 was directly modeled as a function of combined spectral data from both time periods. The rate of change in conifer cover between 1985–1999, while considerable on the time scale of forest dynamics, is within the range of classification error from Landsat modeling. Progress continues to date on appropriate direct change analysis methods to ameliorate these circumstances.

During the summers of 2001 and 2002, 245 forest stands across the GYE, including 57 in YNP, were field sampled for structural and compositional attributes. Progress continues to date on allometrically estimating aboveground biomass and carbon stores and changes in these response variables according to our hierarchical vegetation classification and change detection methods. Progress also continues to date on deriving species abundance models for birds and shrubs as a function of forest stand measurements and biophysical factors.

Project title: Ecology and Community Dynamics of Remnant Grasslands, Western Montana

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Additional investigator: Pamela G. Sikkink

Objective: The objective of this study is to determine the trends of vegetation change over the past 25+ years in the intermountain grasslands of western Montana. We are examining grassland trends at several scales from site to landscape and relating the changes to differences in temperature and moisture, soil characteristics, and changes in land use near all sites.

Findings: We are currently finishing up the historic and current species lists for each site so that trend analysis can begin. In Yellowstone, we have data from 17 line transects and 10 Daubenmire transects that need to be standardized for nomenclature of the historic and current species lists before the lists can be used in trend or time-series analysis. The transects have been taken from both inside and outside YNP exclosures. The main exclosures examined in this study are Gardiner, Blacktail, Lamar and Junction Butte because they historically contained Agropyron and Festuca grasses that are the focus of this study. The vegetation data from these 27 measured lines is only a portion of the data being examined for the complete study of grassland change in the intermountain areas, which ranges from the National Bison Range to Yellowstone National Park. The other areas have similar analysis to complete before time-series analysis can be run for the whole landscape.

Twelve soil samples from YNP have been processed from both inside and outside the YNP exclosures. Total soil samples for the whole project area is 53. Textural analysis of the soils is now completed, as well as analysis of carbon organic matter using loss-on-incineration methods. Phosphorus analysis has been postponed at this time, until we determine if it is needed to separate samples in ordination analyses at the landscape level.

OTHER

Project title: Snow Pack Variation

Principal investigator: Mr. Phillip Farnes
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Objective: Evaluate variability of snow pack across YNP with emphasis on the northern range and determine sinking depths of different bearing pressures on different snow conditions. Data will be used to validate models of snow distribution.

Findings: This is a three-part project. The first is to make snow surveys at weather stations to see how the actual snow water equivalent on the ground compares to the SWE estimated using weather records consisting of snow depth, precipitation, and average daily temperatures. Preliminary results indicate that the estimates correlate reasonably well with actual measurements. Second, snow surveys are taken at six locations on the northern range (three at weather stations) to be used to validate snow models. Presently, there are two or three models in the development phase but none are yet to the validation phase or funding has not been obtained to do the validation. The third part is snow sinking studies at these same six locations where different bearing pressures are brought to bear on the snow surface and the penetration depth is measured. Pressures used vary from about one-half psi up to 26 psi. When finished, it is planned to have data from many different snow depths and snow densities over the span of the snow season.

Results of this study will be used to determine sinking depths of ungulates and predators to determine times and conditions, when traveling over the snow, that the advantage is with the prey species and when the advantage is with the predators. This project will be completed when models have been validated. Reports will be summarized for all three phases at that time.

Project title: Collection for Interpretive Educational Programs

Principal investigator: Ms. Judith Knuth Folts
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Objective: (1) Provide visitor education on cultural and natural history interpretive themes at Yellowstone National Park through the use of interpretive props including, but not limited to, rocks, antlers, bones, fur, feathers, scat, etc.; (2) provide information on park critical resources and management activities to engender an understanding and appreciation of park significance.

Findings: During FY 2002, the Division of Interpretation completed 4,050 formal intrepretive programs, 120 curriculum-based education programs, and 13,315 hours of roving interpretation. More than 500,000 visitors attended the walks, talks, hikes, evening campfire programs, and curriculum-based education programs, or they talked with an interpretive park ranger on rove assignment at campgrounds, pullouts, or wildlife jams. 2,123,083 visitors were contacted at the park's nine visitor centers/contact stations and four winter warming huts.

All interpretive park rangers used various field specimens as interpretive props. These tangible aids assisted visitors in learning about the park's resources, protection methods, and visitor/wildlife interactions. Props are vital to an interpretive park ranger's ability to relate a compelling story to visitors that will engender a stewardhip for America's national parks.

Project title: Vascular Flora of the Greater Yellowstone Area

Principal investigator: Mr. Erwin Evert
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Objective: To collect vascular plant specimens as vouchers for distribution maps to be included in the investigator's "Flora of the Greater Yellowstone Area". For other objectives see Investigator's Research Proposal Outline.

Findings: Five species previously unknown from the park were collected: *Rubus laciniatus*, *Anthoxanthum odoratum*, *Cerastium nutans*, *Hordeum x caespitosum* and *Carex parryana* var. *unica*. Nine other species of interest were collected: *Navarettia intertexta*, *Bromus briziformis*, *Carex buxbaumii*, *C.leptalea*, *C. livida*, *C.limosa*, *Drosera anglica*, *Eriophorum viridicarinatum* and *Astragalus cicer*.

Project title: Studies of Parasitic Wasps (Braconidae) in Yellowstone and Grand Teton National Parks

Principal investigator: Mr. Scott Shaw
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Objective: The goal in YNP was to examine colonies of mound-building building ants (genus *Formica*) for parasitic wasps of the family Braconidae. A specific objective was to search for the ant-associated wasp species, *Myiocephalus boop*s, which had been found in south YNP in two previous studies.

Findings: *Myiocephalus boops* was not found in south YNP, however the species was found in a separate study in Grand Teton National Park (AMK ranch). Because of the difficulty of placing and maintaining

Malaise traps in remote areas, sampling in south YNP was restricted to by-hand collecting with nets and aspirators. Another ant-associated parasitic wasp, a new species of Elasmosoma near pergandei (Family Braconidae, Subfamily Neoneurinae) was discovered in south YNP on 30 July near the South Gate Ranger Station and in areas south of the park entrance. These wasps were observed to be active from 30 July to 9 August. They were observed hovering near nests of *Formica obscuripes* mound-building ants between 9am and noon on sunny days. They were less active on cooler days and during cloudy weather. Samples for description were obtained by aspirator, and have since been compared with type species of Elasmosoma species from the U.S. National Museum of Natural History, confirming the new species status of this insect. A manuscript describing and naming this new species is currently in preparation. Neoneurine wasps are thought to all be internal parasites in the abdomens of adult worker ants, but information on their biology and behavior is sparse.

Project title: Responses of Bison to Simulated Predators and Scavengers

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Additional investigator: Kim Snow

Objective: The objective of this study was to determine the extent to which bison that have been free of predation by woves for more than 50 years respond to cues associated with wolves, scavengers, and neutral species. The response of bison from Yellowstone are to be contrasted with bison from other national parks, including Wood buffalo in Canada where wolves are active predators, and both Grand Teton and Badlands Parks where bison have not been exposed to predators for more than 50 years.

Findings: Bison in Yellowstone exhibited low levels of responses to wolf and raven vocalizations, although the former elicited greater vigilence than the latter. The median responses to these audio cues were generally similar to those of control sounds including red-tailed hawks, running water, and spotted hyenas and lions. However, the variance in responses to wolves was greater than when playbacks were conducted four years earlier, an indication that bison may be starting to respond to sounds of dangerous predators.

PALEONTOLOGY

Project title: Silicification of Vascular Plants in Hot Spring Environments

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Additional investigator: Prof. Dianne Edwards

Objective: (1) Assess the possible environments of higher plant silicification, burial and diagenetic alteration associated with surface geothermal activity; (2) investigate the extent and nature of silica mineralisation within plant material of hot spring environments; (3) determine physicochemical, biochemical and physiological controls on silica permineralisation at cellular to structural levels; (4) compare silica fabrics from Yellowstone plants, sub-fossils and fossils with those of a 400 million year old fossil hot spring deposit at Rhynie, Aberdeenshire, Scotland; (5) investigate the physiological adaptations of modem plants to the sedimentary, hydrogeological and geochemical regimes of modern hot springs and assess the probability of similar adaptive strategies in early terrestrial ecosystems; (6) assess using in vivo and in vitro experimentation rates and sequences of silica mineralisation within plants and plant organs commonly found in Yellowstone sub-fossil sinters.

Findings: SEM observation of plant material displaying incipient silica mineralisation provides evidence of intracellular nucleation, polymerisation and aggregation of sub-micron spheres via colloidal mechanisms. Infilling of intercellular voids occurs rapidly. Rigid silica-particle frameworks form during the first 12 months of immersion.

Silica deposition fabrics and the degradation of plant materials are mediated by the interplay between a suite of physicochemical parameters (notably pH, temperature, cation concentration) and microbial decomposition. Reduction or cessation of fungal activity by hot fluids promote exceptional preservation.

Rapid vertical, lateral and temporal variation in substrate/groundwater temperature, moisture and geochemistry, indicate a degree of tolerance to those conditions in colonising plants. Plant dissemules, xerophytes, halophytes and aquatics occupy and are silicified within definable hot spring sedimentary facies.

Project title: A Continuing Investigation of the Eocene Palynoflora of the Yancey Creek Drainage Basin, Yellowstone National Park, Wyoming

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Additional investigator: Craig A. Chesner, Melissa Stefos

Objective: The purpose of this study is to gain an understanding of the floristics, paleoecology, and paleoclimate of the Eocene Sepulcher Formation in northern Yellowstone National Park. This goal involves the participation of undergraduate geology majors in the actual research and presentation of the findings.

Findings: During the June 2002, some of the students from Eastern Illinois University Geology Field Camp under the supervision of the primary investigator walked in to the Yancey Creek drainage basin and collected six small rocks for palynological analysis. The rocks were taken from an outcrop in the streambed west of Lost Lake.

The volcaniclastic rock samples, from the Eocene Sepulcher Formation, are being processed using standard acetolysis techniques for palynological study in the Eastern Illinois University Geology/Geography Department where the microscope slides containing any recovered palynomorphs will reside. The Sepulcher Formation consists of sedimentary interbeds between volcanic members of the Absaroka Volcanic Supergroup. The Sepulcher deposits (53–49 my, Hiza, 2000) are significantly pre-date the Huckleberry Ridge Tuff (2.0 my), Lava Creek Tuff (600 ky), and the Mesa Falls Tuff (1.3 my) associated with the major caldera forming events in the park. Sedimentological examination of the volcaniclastic rocks may yield limited insight into the depositional environment in the park during the Eocene.

Table1. List of palynomorph taxe found in the Eocene Sepulcher formation at Yancey Creek, Yellowstone National Park, Wyoming.

Taxa	Common Name
Sphagnum	peat moss
Polypodiaeae	fern
Picea	spruce
Abies	fir
Pinus	pine
Spagnaceae	peat moss
Nymphaea	water lily
Acer	maple
Quercus	oak
Genmcanadense (Rosaceae)	Canadian arens
Carya (Juglandaceae)	pecan
Carya (Juglandaceae)	water hickory

Celtis (Ulmaceae)	hackberry
Prunus	chokecherry
Chamaecyparis/Cupressus	cedar/cypress
Betula	birch
Fagus?	beech

These findings are consistent with those of previous workers. The total number of identified grains at this time is insufficient to make any reliable paleoclimatic or ecological interpretations. Initial impressions certainly suggest the presence of a mixed coniferous-deciduous forest during the Eocene. This project is ongoing with samples collected during the summer of 2001, more samples were collected during the 2002 field season and are undergoing preparation and analysis.

Project title: Recognizing the Signatures of Hyperthermophilic Biofilms: Geyserite, Epithermal Deposits and Ancient Cherts

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Objective: Identify the various types of hyperthermophilic biosignatures preserved in active thermal spring precipitates to improve the ability to recognize them in the geological record. Biosignatures include microfossils and microbial remains, organosedimentary structures and fabrics, and chemical fossils (biomarkers, biominerals, geochemical markers, isotopic signatures). Since hyperthermophiles occur as biofilms on actively accreting surfaces of hot spring deposits, they influence the fabric and structures of the hot spring sinter deposit. In those cases where organic remains are preserved in association with the fabrics and structures, a corroborating suite of biosignatures can be recognized.

Findings: No activities took place during the reporting year. Gaining insight into the mechanisms by which microorganisms interact with their environment and how they leave behind a record of this interaction are ongoing research aims of this project.

PLANT COMMUNITIES

Project title: Physiology of Thermotolerant Plants in Yellowstone Park

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Additional investigator: Thamir Al-Niemi

Objective: Our chief objectives during 2002 were threefold. First, to genetically analyze individuals of the plant species *Dichanthelium lanuginosum* (hot springs panic grass) collected from several geothermal locations within YNP. These locations included Norris Geyser Basin, Amphitheater Springs, Rabbit Creek Basin, Firehole River area, and Forest Springs geyser area. Secondly, we collected individuals of *D. lanugonosum* and other plant species, namely, *Panicum capillare*, *Agrostis scabra*, *Juncus tweedii*, *Rumex acetosella*, and *Gnaphalium chilense*, to be analyzed for the expression of heat shock proteins (HSPs). We were interested in HSPs because they may be involved in heat tolerance mechanisms in plants. Finally, some of the plants we collected above were examined for the presence of microbes, especially fungi living inside the plants.

Findings: With regard to our first objective, we have obtained further evidence supporting the idea that genetically distinct populations of *D. lanuginosum* may exist within YNP. This evidence is based primarily on "DNA fingerprint" profiles of individuals collected from different locations within YNP (see objectives above). Further analyses will be required, however, to provide statistically significant data. With regard to the HSP experiments, we found that all of the plant species collected from thermal locations expressed several prominent HSPs. This is the first report, as far as we know, of such HSP expression demonstrated in field-collected plants from geothermal environments. We plan to continue analyzing for the presence of additional classes of HSPs that are suspected of contributing to plant thermotolerance. Finally, our examination of plant-microbe associations in *D. lanuginosum* collected from YNP confirmed the presence of the endophytic fungus *Curvularia*. Moreover, evidence was obtained that both the plant and fungus mutually benefit from this association with regard to thermotolerance. We plan to continue characterizing the nature of this plant-fungal mutualism, especially with regard to level of fungal infection in the plant as well as to the differential gene expression elicited.

Project title: Aspen Regeneration in Northern Yellowstone National Park

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Additional investigators: Roy A. Renkin, Eric J. Larsen, Douglas W. Smith

Objective: Our objective was to measure aspen regenerative success on YNP's northern range. Based on trophic cascades theory, we hypothesized that wolves may displace elk from some areas of the northern range, thus allowing more robust aspen regeneration in areas of higher wolf presence. Permanent 1 x 20 m aspen belt transects (plots) were established in 1999, marked with both a metal identification tag on a large-stemmed aspen tree and nails in the ground at 3, 5,10, and 20 m from the starting point. Subsequently, we have monitored aspen growth and ungulate browsing intensity in our 112 permanent aspen plots.

Findings: A third year of field data were collected from our permanent aspen plots during August of 2002. Aspen overstory density and diameter at breast height (DBH) were recorded and compared to data from 1999 and 2001. Information describing aspen ramet density, height, and browsing intensity was obtained and compared to data from 1999 and 2001. The number of ungulate pellet groups present was recorded for each plot. Our data continues to demonstrate an overall trend of high ungulate browsing pressure on most northern range aspen stands. We are developing an approach to combine our aspen plot results with other sources of data to study the possible effects of a three-level trophic system (wolves, elk, and aspen) on the regeneration of aspen and other woody browse species.

Project title: Ecological, Physiological, and Molecular Biological Studies of Fungi from Geothermal Soils and Thermotolerant Plants in Yellowstone National Park

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Additional investigators: Joan Henson, Regina Redman, Kathy Sheehan, Marilyn Roossinck

Objective: The objective of the study was to determine if symbiotic fungi contribute to the survival of a native plant (*Dichanthelium lanuginosum*) in geothermal soils. This involved comparing the fitness of symbiotic and non-symbiotic plants in geothermal soils and controlled environments over a one-year period.

Findings: The findings of this study were very dramatic. The fitness of *Dichanthelium lanuginosum* under laboratory and field conditions was greater in symbiotic plants versus nonsymbiotic plants. In fact, at temperatures greater than 40°C nonsymbiotic died while symbiotic plants survived. This was the first demonstration that a fungal symbiont was responsible for thermotolerance in plants. More importantly, it suggests that symbioses, rather than plants alone, adapt to selective pressures. This may have significant impacts on habitat restoration strategies.

Project title: Parkwide Seedbank

Principal investigator: Eleanor Clark
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Additional investigators: Sam Reid, Joe Scianna, Paul Anderson, Mark Majerus, Lori Gruber, Orvin Loterbauer, Susan Winslow, Stephanie Cochrane, Al Bowers

Objective: Collection of native seed, native plant cuttings, and native root cuttings for revegetation purposes on highway and building construction projects. Establishment of a parkwide seedbank for revegetation purposes throughout the park.

Findings: During the 2002 season, 154 seed collections were made from 66 species: 44 grasses (14 species) at 28.86 pounds; 99 forbs (44 species) at 34.87 pounds and 11 shrubs/tree at 1.8 pounds. The wildland seed collections totaled 65.52 pounds.

Fifteen different collections of cuttings were made from eight species of native plants producing 433 wildland plants at the Yellowstone Park nursery.

Project title: Ecology and Evolution of Geothermally Adapted *Agrostis* (Bentgrass) of North America and the Kamchatka Penninsula

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Additional investigator: Michael Tercek

Objective: (1) To determine the genetic and phylogenetic relationships among *Agrostis* (Bentgrass) taxa that are endemic to thermal habitats in YNP, Lassen Volcanic National Park, and the Valley of the Geysers, Kamchatka, Russian Federation; (2) to determine whether the endemic Agrostis are valid, monophyletic taxa which are distinct from non-thermal congeners; (3) to determine which ecological factors control the local distribution of the endemic thermal *Agrostis*, particularly *A. rossiae*.

Findings: *Agrostis* species have been known to rapidly evolve ecotypes in response to geographically localized variations in soil chemistry. Two *Agrostis* taxa occur in the geothermal habitats of Yellowstone National Park: *Agrostis rossiae* is endemic to Yellowstone, and *Agrostis scabra* occurs both in the thermal areas and in a variety of non-thermal habitats. I noticed that every thermal population of Agrostis is surrounded by a non-thermal population of *A. scabra* that is reproductively isolated from the thermal area by its later flowering time. This suggested that ecotype evolution had happened twice, producing thermal *A. scabra* and *A. rossiae* in separate events. I used randomly amplified polymorphic DNA (RAPD) markers to resolve the historical relationships among the Yellowstone thermal populations, the non-thermal *A. scabra* populations, seven other non-thermal *Agrostis* species that occur in Wyoming, and thermal *Agrostis* populations in California and Kamchatka. Contrary to my original hypothesis, I found that none of the populations of the thermal taxa are ecotypes of non-thermal *Agrostis scabra*, but instead constitute a single, previously unrecognized endemic taxon that currently has four names. A UPGMA phenogram showed that while the thermal populations form geographically distinct subclusters, populations of the two morphologically distinct thermal taxa (*A. rossiae* and thermal *A. scabra*) do not cluster independently. Even though currently confused with the thermal populations, nonthermal *A. scabra* does not appear to be closely related. I used a series of field and laboratory experiments, as well as extensive field monitoring, to show that there are no important ecological differences between *A. rossiae* and thermal *A. scabra*. The ecological factor primarily responsible for the geographic separation of the thermal and non-thermal populations is the seasonal fluctuation of soil temperature relative to the life cycle of the plants. Lethal summer soil temperatures in the thermal areas are selecting for precocious flowering and an annual habit, which excludes the more slowly maturing nonthermal plants. The thermal plants, in contrast, do not grow in the non-thermal matrix in prevailing cool field temperatures, but do grow in these habitats under artificially elevated temperatures. The thermal taxa may have reduced competitive ability at cooler temperatures.

PROTISTA

PROJECT TITLE: MICROBIAL PHYSIOLOGY AND ECOLOGY: DNA DAMAGE AND PHOTOSYNTHESIS

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Additional investigators: Catherine Tsairides, Vanessa Lancaster, Dana Rogoff, Rocco Mancinelli

Objective: The role of microbial physiology and ecology is important to understand early evolution of life on earth, and the potential for life to survive and evolve elsewhere. While much is known about microbial physiology and ecology in the lab setting, much less is known about microbial functioning in nature. Our research in Yellowstone bridges this gap by asking: how do organisms survive and adjust to their environment in nature? Yellowstone is used for two reasons. First, there are a variety of microbial ecosystems, which make nice models for generalized microbial ecosystems. Second, there are a number of ecosystems in extreme environments (low pH, high temperature, etc.) that may be good models for life on early earth or elsewhere in the universe.

Findings: In 2002, research focused on the effects of UV radiation and hydrogen peroxide on microbial mat communities in Norris Geyser Basin and Octopus Spring. We found that UV radiation enhances DNA synthesis rates during the day, which we interpret as being indicative of excision repair. However, previous work suggests that the damage may be due to UVA effects mediated through oxidative damage rather than the direct effect of UVB. Experiments adding hydrogen peroxide to sample showed an increase in DNA synthesis in response to small amounts of additional hydrogen peroxide, and a decrease in response to high levels, with another increase at even higher levels, about 1 mM for Octopus and *Zygogonium* mat. At the very highest concentrations of H^2O^2, DNA synthesis, of course, drops to zero, probably an indication of cell death. For all the mats studied, DNA synthesis stopped by 1 M H^2O^2. Pre-challenging *Zygogonium* with H^2O^2 prior to measuring the effect of H^2O^2 on DNA synthesis decreased the subsequent rate of DNA synthesis. This is suggestive of an induction of catalase. The effect of several drugs were tested on the effect of H^2O^2 on DNA synthesis. Caffeine (1 mM) increased DNA synthesis in the presence and absence of additional H^2O^2 in *Cyanidium*, *Zygogonium*. Theses two algal species have shown response to increasing H^2O^2 concentrations and indicate not only a mitotic response to the peroxide levels but also several DNA repair mechanisms including excision repair have been indicated from the data collected in the last field season 2002. The four trips in May through September allowed us the measure the change in response to the increase and decrease in UV radiation of these two species, with and without the addition of H^2O^2.

SOCIAL SCIENCE

Project title: The Economic Value Associated with Substitution Away from Yellowstone National Park as a Unique Recreation Site

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Additional investigator: Chris Bastian

Objective: (1) Complete a survey of snowmobilers using Yellowstone National Parke which addresses their substitution to another site should YNP be closed to snowmobile use; (2) estimate a Random Utility Model from the survey data that estimates probabilities of potential use of substitute sites and changes in recreation benefits associated with those substitutions; (3) compare actual substitution to state preference responses regarding estimated probabilities and benefits in a random utility model of recreation demand.

Findings: The survey was completed in the 2001–02 season. A total of 1,148 surveys were mailed and 702 responses were received back for a response rate of 61%. Preliminary descriptive statistics indicate respondents would decrease their snowmobile trips to Wyoming, Idaho and Montana by half if Yellowstone National Park were closed to snowmobiling.

Currently the estimation of the Random Utility Model is behind schedule. It is hoped full results achieving our objectives will be obtained by December 2003.

Project title: Yellowstone–Grand Teton Winter Visitor Survey

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Objective: The objective of the study is to collect information that will be used to support a rulemaking about winter management of the parks. We will intercept a random sample of winter visitors to Grand Teton and Yellowstone National Parks. The selected visitors will be mailed a survey with questions about their current trip (where they visited, their activities, and their expenditures), their preferences for different winter activities in the parks, their winter recreation in the previous year, and demographic characteristics.

Findings: We started data collection the week of December 18, 2002, and will continue through mid-March 2003.

Project title: Front-End Evaluation for Old Faithful Visitor Education Center Exhibits

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Additional investigator: Eric Gyllenhaal

Objective: The Yellowstone Park Foundation, in partnership with Yellowstone National Park, is spearheading a major capital campaign to design and build a new 43,000 square foot visitor education center at Old Faithful Geyser. The primary theme for the exhibits is: Yellowstone National Park protects the rarest collection of geysers and hot springs on Earth.

In order to tell the complete hydrothermal story of Yellowstone, it was recognized that visitors could quickly be overwhelmed with too much information. Consequently, the study was designed to determine what visitors know about the unique hydrothermal features when they arrive in the park and what is most important to them to learn and experience. The study was also to determine if the scope and breadth of the thematic outline for the exhibits is realistic, appropriate, and achievable considering the parameters of audience, time constraints, interest level, and other competing opportunities for recreation and education in Yellowstone. The results of the front-end evaluation will be used by the exhibit planners, writers, and designers, giving them direction as they develop the style and depth of the exhibits.

Findings: The overarching research question for this front-end evaluation was: What can we learn about actual and potential visitors' understanding, feelings, and expectations about Yellowstone's geyser basins that will help us make the new visitor eduction center exhibits exciting, inspiring, and informative for the broadest range of visitors?

The evaluation was conducted from early August through late September. Naturalistic methodology was used to conduct the study and included in-depth on-site and phone interviews with visitors both before and after their visits and the use of card sorts and drawing activities. Respondents were purposively selected in order to talk to people who are as different from each other as possible in order to elicit the widest range of responses.

Respondents said that they came to Old Faithful for a variety of reasons, but many visitors felt they had to see Old Faithful Geyser during their Yellowstone trip. Learning played a moderately important role in visitors' Yellowstone experience. Respondents had trouble connecting what they already understood about geology and the earth's subsurface to the hydrothermal features they saw here. Key steps in building visitors' understanding seemed to be realizing that the geyser basins of Yellowstone lie withing an active volcano and then understanding the "plumbing system" that circulates water from the subsurface to the park's geysers and other hydrothermal features. Many respondents emphasized the importance of scientists communicating directly with the public. Respondents stressed that exhibits in the new visitor center must be interactive, hands-on, and "fun for the kids." Respondents also strongly believed that the next predicted eruption time for Old Faithful needs to be prominently displayed in many places.

Numerous recommendations for exhibit planning and design resulted from the study. For the primary theme (Yellowstone protects the rarest collection of geysers and hot springs on Earth), it was suggested that the exhibits focus on the wealth of hydrothermal features of Yellowstone, helping visitors understand why these geysers and hot springs are unique. It was also suggested that visitors need to better understand the meaning of "protect." All of the sub-themes planned for the exhibits should be included, but an ordering of the material is essential as well as the recognition that much of the material is highly scientific and needs to be simplified. Hands-on exhibits that challenge and arouse curiosity will be important. Other recommendations are included in the final report.

THREATENED AND ENDANGERED SPECIES

Project title: Yellowstone Gray Wolf Restoration Project

Principal investigator: Dr. Douglas Smith
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Objective: To restore the gray wolf to the Yellowstone Recovery Area while learning about their biology, ecology, ecosystem effects, and unique aspects of their return. Also, to aid Yellowstone National Park management in a fashion that benefits wolves and humans. All work will be accomplished in a safe manner.

Findings: Approximately 148 wolves in 14 packs were present in Yellowstone National Park in 2002 with ~67 pups born to 12 packs and ~7 adult wolves dying of various causes. The population increased by 11%. There were 137 definite, 187 probable, and 4 possible kills made by wolves, with 84% of them elk, and the rest bison, deer, coyote, pronghorn, badger, or Canada goose. The composition of elk kills was 36% calves, 34% cows, 19% bulls, 6.5% elk of unknown sex, and 3.5% elk of unknown sex and age. Average winter kill rate of northern range wolves was 1.8 elk/wolf/30-day study period.

Project title: Population Dynamics of the Yellowstone Grizzly Bear

Principal investigator: Dr. Charles Schwartz
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Additional investigator: Mark Haroldson

Objective: To determine population status and trends of the Yellowstone grizzly bear.

Findings: These data include information collected by the Interagency Grizzly Bear Study Team (members include U.S. Geological Survey, Yellowstone National Park, Wyoming Game and Fish, Idaho Fish and Game, Montana Fish, Wildlife and Parks, U.S. Fish and Wildlife Service, U.S. Forest Service) for the entire Greater Yellowstone Ecosystem. Data obtained within Yellowstone National Park is not broken out separately.

Fifty-three individual grizzly bears were captured a total of 71 times during the 2002 field season in the Greater Yellowstone Ecosystem (GYE). Twenty-eight captures were new individuals that had not been previously marked. Twenty-one captures of 20 bears were the result of management trapping efforts. Fifteen of these instances resulted in relocation of the nuisance bear(s). A total of 911 aerial radio locations were obtained from 83 individual grizzly bears radio-monitored during all, or a portion of the 2002 field season. Thirty of the grizzly bears radio-monitored were adult females. Two rounds of observation flights were conducted as part of our effort to count unduplicated females with cubs-of-the-year and document distribution of females with young (cubs, yearlings, or two-year-olds). The first round of flights began 12 June. One hundred eighty-eight grizzly bears were observed in 125 groups during 84 hours of flying. The second round of flights began on 13 July. A total of 269 grizzly bears in 169 groups were observed during 79 hours of flying. Eighty females with young were observed during observation flights; 29 of these were initial observations of unduplicated females with cubs-of-the-year. Fifty-two unduplicated females with cubs were identified during 2002. A total of 102 cubs were observed during the initial sightings of unduplicated females. Fourteen single cub litters, 26 litters of twins, and 12 litters of triplets were observed. Mean litter size was 1.96. Unduplicated females with cubs were observed in 13 of 18 Bear Management Units (BMU) within the grizzly bear recovery zone. Females with young (cubs, yearlings or two-year-olds) were documented in all 18 BMUs. We documented 16 known, and 1 possible human-caused grizzly bear mortalities in the GYE during 2002. Fourteen human-caused mortalities, including seven females, occurred within the USFWS Recovery Zone and 10-mile perimeter. Seven losses were from management removals, including one bear that was initially translocated, but became involved in a subsequent conflict and was removed. Three and four management removals occurred in Wyoming and Montana respectively. Three natural mortalities were documented. An additional three grizzly bears died from unknown causes were documented during 2002.

Project title: Food Habits and Habitat Use of the Yellowstone Grizzly Bear

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Additional investigators: Shannon Podruzny, Mark Haroldson

Objective: To determine habitat requirements for the Yellowstone grizzly bear.

Findings: These data include information collected by the Interagency Grizzly Bear Study Team (members include U.S. Geological Survey, Yellowstone National Park, Wyoming Game and Fish, Idaho Fish and Game, Montana Fish, Wildlife and Parks, U.S. Fish and Wildlife Service, U.S. Forest Service) for the entire Greater Yellowstone Ecosystem. Data obtained within YNP is not broken out separately.

Surveys to determine an index of spring ungulate carcass availability were conducted during May. Approximately 300 km of transect routes were surveyed in four different ungulate wintering areas. A total of 14 elk and 11 bison carcasses were observed for a rate of 0.09 ungulate carcasses/km. These results indicate a relatively small number of winter-killed ungulates were available to bears during the spring of 2002. Surveys of 19 whitebark pine cone productivity transects distributed throughout the Greater Yellowstone Ecosystem were completed during July. Mean cones per tree for the read transects were 2.5. Transects in the northern part of the ecosystem exhibited higher cone production than those in the southern and eastern portions. This pattern of cone production was similar to those observed during 2001. A total of 268 grizzly bear observations, in 187 groups, were recorded at 26 of 50 army cutworm moth aggregation sites identified through 2001. Grizzly bears were observed digging in talus, presumable for moths, at 4 additional, previously unknown sites during 2002.

VASCULAR PLANTS

Project title: Cottonwood Age and Diameter Relationships in Yellowstone's Northern Range

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Objective: To establish age vs. diameter relationships for cottonwoods in the Lamar Valley (that portion upstream and downstream of the Buffalo Ranch and also the lower portion of Soda Butte Creek). Such information is needed to better understand the long-term stand dynamics and the influences of various factors on cottonwood recrutment.

Findings: Cottonwood diameter data were collected for groves in the Lamar Valley and lower Soda Butte Creek in late summer 2002. Over 50 cores from live and recently dead (due to recent bank erosion) cottonwoods were obtained. Cores are currently being analyzed.

Project title: Yellowstone Flora

Principal investigator: Ms. Jennifer Whipple
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Objective: The vascular plant flora of Yellowstone, even though investigated for approximately 120 years, is not completely known. The primary focus of this project is to improve the current knowledge of the flora of the park through in-depth collecting, especially of areas in the park which have not been previously studied. This includes inventory of the occurence and range of native taxa and also involves the documentation of the arrival and spread of exotic species. In addition, collection of specimens for the Yellowstone herbarium will improve the value of the facility for both NPS personnel and outside researchers.

Findings: Ongoing inventory of vascular plants and collection for the Yellowstone National Park Herbarium (YELLO). Two species of native vascular plants previously not reported for Yellowstone were discovered, golden currant (*Ribes aureum*) and purple avens (*Geum rivale*). Previous reports of Brown's peony (*Paeonia brownii*) were based on a specimen in YELLO that was actually collected just outside of the park. A small population of Brown's peony was found just inside the park's boundary in Bechler. Aunt Lucy (*Ellisia nyctelea*) was confirmed to be in the park, since no herbarium specimens documenting the report of this species had been located. Five new exotic species were also discovered within the park; tomato (*Lycopersicon esculentum*), spring speedwell (*Veronica verna*), small-flowered alyssum

(*Alyssum parviflorum* var. *micranthum*), colonial bentgrass (*Agrostis capillaris*), and roughstalk bluegrass (*Poa trivialis*).

Project title: Taxonomy of Orobanche Section Myzorrhiza

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Additional investigators: Turner Collins, George Yatskievych, Kendra Kinnan

Objective: The purpose of this study is to develop a revised key to the species of Orobanche (Section Myzorrhiza) of North America and to refine the existing understanding of the relationships within this rarely seen genus of parasitic plants. In order to update the information available on this genus, we have been making collections of these plants from localities which have previously yielded unusual or problematic specimens. The vicinity of Yellowstone National Park is of interest for the following reasons: The ranges of two of the widespread species in this group, *O. corymbosa* and *O. ludoviciana*, overlap in the region of Yellowstone National Park. In addition, there was a single unusual specimen of Orobanche collected by F.H. Buglehaus near Mammoth Hot Springs in July of 1894, which previous researchers have speculated might represent an undescribed taxon. We are seeking to document the continued presence of both of these Orobanche species in the vicinity of Yellowstone National Park, and to determine whether the unusual specimen from Mammoth Hot Springs is a hybrid between these two species, a local variant of one of these species, or indeed a separate entity.

Findings: In September 2002, we were able to visit five of six localities within YNP that the park botanist had previously documented to contain Orobanche. With the guidance of the park botanist, we were able to find Orobanche in bloom or dried inflorescences at four of these sites, an unusually high rate of success for this rare, ephemeral species. We were able to confirm the host plant species at three sites. The host on *O. ludoviciana* comb nov in hot springs sites was *Chrysopsis depressus*. The host on a putative hybrid population near Antelope creek was *Artemisia tridentata*. The host of *O. corymbosa* at Old Faithful Village was probably *Chrysopsis depressus*. We were able to verify that the specimens occurring in hot springs sites were indeed unique in some morphological traits. DNA was extracted from Orobanche specimens collected at all four sites and sequence analysis for two genes is under way.

WATER QUALITY

Project title: Trophic Classification of Selected Lakes in Yellowstone National Park

Principal investigator: Dr. Woodruff Miller
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Objective: Evaluate the trophic state of lakes in the greater Yellowstone ecosystem.

Findings: This year I did not conduct my field studies in Yellowstone Park, but rather in the Wind River Mountains region of the greater Yellowstone ecosystem.

WATER RESOURCES

PROJECT TITLE: STUDY PLAN TO EVALUATE THE EFFECTS OF THE PROPOSED SNOWFLAKE SPRING CREEK PROJECT

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Objective: The objective of this study is to ascertain the effects—both positive and negative—that might result to the fisheries of the West Gallatin River from the implementation of a proposed created mile-long spring creek using waters from the Snowflake Springs. The study will be used to potentially alter the design of the project, or if adverse impacts are unavoidable, the results of the study will lead to the termination of the project. The study reach is four miles long, of which one mile is within the park.

More specifically, the purpose of the study is to: describe the current status of fisheries resources in the West Gallatin River in the general area of the project, including species composition, distribution, abundance, and age/size class structure; evaluate the physical habitat and water quality conditions in the river, adjacent tributaries, the existing spring-fed channel, and the proposed channel; assess the importance of the adjacent tributaries, including the existing spring-fed and proposed channels, to the production and overall status of the West Gallatin River fishery; and assess the importance of the spring flows to the West Gallatin River, particularly the beneficial thermal effects during the winter, and the anticipated changes and effects resulting from the proposed project.

Findings: To date, the following baseline data has been collected: brown trout redd counts in Snowflake Springs; fall and winter discharge measurements in the river and springs; survey of river cross-sections every 500 feet; and installation of nine HOBO continuous recording temperature probes (one of which is in the park).

Work to occur in the winter and spring of 2003 will include surveys of ice levels, rainbow trout redd counts, and water temperature.

No data analysis has yet occurred.

WATERSHED MANAGEMENT

Project title: Reference Stream Monitoring—Long-term Trend Sites

Principal investigator: Mr. Scott Collyard
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Additional investigators: Jason Martineau, Jeremy Zumberge

Objective: The Department of Environmental Quality, Water Quality Division (DEQ/WQD), has been collecting long-term monitoring data for water quality, macroinvertebrate, and habitat at least impacted, reference stream sites in Yellowstone National Park. The data, along with other reference stream data collected throughout the state, will be used to help assess the quality of water at other sites that have been listed as impaired by the State of Wyoming. The State of Wyoming has been conducting its Beneficial Use Reconnaissance Program (BURP) on streams that have been listed as impaired, but have been lacking in credible data to support the impairment. The water quality, macroinvertebrate and habitat data that is collected at these sites will be compared to representative reference stream sites in the state to help judge impairments.

Findings: Ongoing monitoring of long-term reference site with no final report available at this time.

Project title: Yellowstone Lake Tributary Stream Characterization Using Remote Sensing (Advanced Thermal and Land Applications Sensor or Atlas)

Principal investigator: Mr. Tom Olliff
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Additional investigators: Kerry Halligan, Robert Crabtree, Todd Koel

Objective: The objective of this study is to test the application of high resolution multispectral or hyper-spectral imagery to characterizing key spawning streams for Yellowstone cutthroat trout surrounding Yellowstone Lake.

Findings: We conducted a demonstration project to characterize key spawning streams for Yellowstone cutthroat trout surrounding Yellowstone Lake utilizing high-resolution multispectral or hyperspectral imagery, which includes thermal infrared channels for the retrieval of water temperature. We were attempting to characterize three categories of streams (geothermally influenced streams, large streams and small streams) by temperature, morphological properties, and riparian vegetation using these remote sensing data and sophisticated image analysis techniques. The project began in July 2002 with the collection of remote sensing data as well as concurrent collection of pertinent field data. Streams studied included Hatchery Creek, Bridge Creek, Arnica Creek, Little Thumb Creek, Sewer Creek, 1167 Creek, 1158 Creek, 1138 Creek, Trail Creek, Beaverdam Creek, Clear Creek, and Pelican Creek. In conjunction with NASA, we flew the Advanced Thermal and Land Applications Sensor (ATLAS), a 15-channel (visible to far infrared) flown on the NASA Stennis Lear jet. ATLAS is able to sense 15 multispectral radiation channels across the thermal, near-infared, visible spectrums. The sensor also incorporated onboard, active calibration sources for all bands. ATLAS flew approximately 4,000 ft above the ground and collected approximately 2.5 meter resolution per pixel. The flights were conducted in one day. No specimens were collected. Data were received from NASA in January 2003 and is currently being analyzed.

There will be no more fieldwork associated with this project. A final report is due October 2003.

WETLANDS

Project title: Hydrogeomorphic Approach to the Assessment of Wetlands in Yellowstone National Park

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Additional invesitgators: Bob Leinard, Jim Doolittle, Mike Gilbert, Marcus Miller

Objective: Collect data on undisturbed wetlands for characterization and scaling of variables for wetland assessment methods in the northern Rocky Mountains.

Findings: Work was never completed due to lack of funding.

Project title: Assessing Ecosystem Integrity: An Approach to Modeling Energy Flow

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Objective: Determine wetland aquatic invertebrate production and energy flow from wetlands.

Findings: Study suspended due to lack of funding.

Index of Investigators

D

E

F

G

H

I

J

K

L

M

N

O

P

Q

R

S

T

V

W

Y

Z